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JUDGMENTS OF RELATIVE NOISINESS OF A SUPERSONIC TRANSPORT AND SEVERAL COMMERCIAL-SERVICE AIRCRAFT

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16. Abstract

Two laboratory experiments have been conducted on the relative noisiness of takeoff and landing operations of a supersonic transport and several other aircraft in current commercial service. A total of 96 subjects made noisiness judgments on 120 tape-recorded flyover noises in the outdoor-acoustic-simulation experiment; 32 different subjects made judgments on the noises in the indoor-acoustic-simulation experiment. The judgments were made by using the method of numerical category scaling.

The effective perceived noise level underestimated the noisiness of the supersonic transport by 3.5 dB. For takeoff operations, no difference was found between the noisiness of the supersonic transport and the group of other aircraft for the A-weighted rating scale; however, for landing operations, the noisiness of the supersonic transport was overestimated by 3.7 dB. Very high correlation was found between the outdoor-simulation experiment and the indoor-simulation experiment.

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SUMMARY

Two laboratory experiments have been conducted on the effectiveness of various noise rating schemes in predicting the relative noisiness of takeoff and landing operations of a supersonic transport and five other aircraft currently in commercial service. In one experiment, 96 subjects made noisiness judgments on 120 tape-recorded flyover noises presented in an outdoor-acoustic-simulation facility. In the other experiment, 32 different subjects made judgments on the same noises presented in an indoor-acoustic-simulation facility. The judgments were made by using the method of numerical category scaling.

The noises were recorded on the center line very near the locations specified for FAR 36 certification. The subjective judgments from both experiments were compared with acoustical analyses of the noises in terms of some of the more common physical-measurement procedures or rating scales. The results from the outdoor- and the indoor-simulation experiments were remarkably similar. The effective perceived noise level was found to underestimate the noisiness of the supersonic transport by 3.5 dB. For takeoff operations, no difference was found between the noisiness of the supersonic transport and the group of other aircraft for the A-weighted rating scale; however, for landing operations, the noisiness of the supersonic transport was overestimated by 3.7 dB. Duration corrections, in general, improved the predictive ability of the rating scale; however, tone corrections (FAR 36 method) reduced the predictive ability.

INTRODUCTION

The introduction of any new, or different type of, aircraft into regular commercial service usually poses the question of how well the currently used physical-noise-measurement procedures or rating scales predict, for the new noise source, those subjective attributes associated with annoyance. Considerable research concerned with subjective evaluations of the aircraft-noise scaling procedures has been performed, as evidenced by the extensive bibliographies on the subject in references 1 and 2. The general consensus of this past research is that while no one rating scale or procedure can be clearly shown to be superior to all others, under specific test conditions or for specific noise sources, some of the procedures are more applicable than others for predictive purposes.

The introduction of the Concorde supersonic transport into the fleet of commercial aircraft operating within the United States of America has similarly raised questions concerning the ability of the rating scales to predict the subjective response of people to supersonic-transport noise. In addition to the higher noise levels, several secondary spectral and temporal differences, which could be of subjective importance, were reported in the environmental impact statement from reference 3. The spectral differences result from the different types of engines used by supersonic and modern subsonic jet aircraft. Over the past decade, subsonic jet aircraft, in an effort to reduce noise levels, have reduced exhaust velocities through the use of turbofan engines with increasingly higher fan bypass ratios. Supersonic aircraft, on the other hand, require the higher exhaust velocities of turbojet engines to achieve efficient supersonic flight. These turbojet engines give rise to distinct spectral differences when compared with turbofan engines that are characterized by significant tonal components. The temporal distinction results from the significantly higher airspeed during takeoff and landing operations for a supersonic aircraft. The noise duration, the time the noise level exceeds the peak level minus 10 dB, is, therefore, reduced somewhat in areas under the flight path and near the airport. However, because of the spectral differences and the frequency dependent nature of atmospheric attenuation of sound, the advantages of higher airspeed on noise duration quickly diminish as slant range distances increase.

The main purpose of the research effort reported herein is to provide general information on the predictive ability of some of the more common noise rating scales for quantifying the noise of several aircraft, including a supersonic transport. Two separate laboratory experiments were conducted. In one experiment, 96 subjects made numerical-category-type judgments on a total of 120 recorded aircraft noise stimuli in a simulated outdoor acoustic environment. The noises included both takeoff and landing operations of a Concorde supersonic transport and five other commercial airplanes: DC-8 turbofan, DC-8 turbojet, B-747, B-737, and CV-640 turboprop. In the other experiment, 32 subjects made the same type of judgments on the same set of stimuli but in a simulated indoor acoustic environment. Results are presented in terms of several of the more common rating scales, and comparisons are made between the results of the indoor- and the outdoor-acoustic-simulation experiments.

ABBREVIATIONS

The following rating scales have been used in the acoustical analyses of the aircraft noises used in the reported experiments. Additional descriptive information concerning frequency weightings and computational procedures can be found in reference 4.

EPL duration corrected perceived level according to Stevens Mark VII procedure with energy averaging over duration, EPLdB

EPNL effective perceived noise level, EPNdB

L_A peak A-weighted sound pressure level, dB

L_D peak D-weighted sound pressure level, dB

PL perceived level according to Stevens Mark VII procedure, PLdB

PNL perceived noise level, PNdB

PNLT tcne corrected perceived noise level (FAR 36 procedure), PNdB

Subscripts:

1 sound level meter set for "slow" time averaging with 22.5-Hz to 22.5-kHz bandwidth

2 analog one-third-octave band analysis, digital root-mean-square detection, digital time integration of 0.5 sec, 50-Hz to 10-kHz one-third-octave bands used in analysis, digital frequency weighting

Other abbreviations used herein are:

ANSI American National Standards Institute

ENL equal noisiness level

FAR Federal Aviation Regulation

TF turbofan

TJ turbojet

EXPERIMENTAL DESIGN AND PROCEDURE

Noise Stimuli

The stimuli used in these experiments were loudspeaker-reproduced tape recordings of aircraft takeoff and landing operations. The maximum noise levels presented to the subjects are given in table I in terms of some of the more common measurement or rating scales. Each of the listed stimuli was presented to the test subjects at five different levels. The master recordings of the Concorde noises were obtained from the British Aircraft Corporation and those of the other aircraft noises were obtained on contract from MAN-Acoustics and Noise, Inc. All noises were recorded at locations under the flight path near the FAR 36 noise certification measurement locations of 6.49 km for takeoff operations or 1.85 km for landing operations. Time histories for each type of flyover noise as measured in L_{D1} for the outdoor simulation experiment are presented in figures 1(a) to 1(f). As can be seen from these figures, the set of noises used in the experiments represents a fairly wide range in duration. Some obvious truncations of the time histories are also apparent. This was necessary because of extraneous background noises in the original recordings. However, in no case did the truncation prevent at least a 20-dB rise and decay in the natural time history. During preparation of the actual presentation tapes, the highest level of each stimulus was adjusted so that each produced approximately equal peak L_{D1} at the recorder output. This was done to approximate equal PNL levels for each type of stimulus. The lower levels of each stimulus were produced at -8 dB, -16 dB, -24 dB, and -32 dB relative to the overall sound pressure levels of these highest levels.

One-third-octave analyses of the stimuli occurring during the 0.5-sec interval at peak PNL are shown in figures 2(a) to 2(f). From these figures it can be seen that, as would be expected, spectral compositions of the Concorde stimuli were generally similar to those of the DC-8 turbojet stimuli. For both of the aircraft, no high-frequency tone components were evident. On the other hand, significant tone components were evident in the B-747, DC-8 turbofan, B-737, and CV-640 landing noises and in the B-747 and DC-8 turbofan takeoff noises.

Test Subjects

The subjects used in both experiments were randomly selected from a pool of local residents with a wide range of socio-economic backgrounds and were paid to participate in the experiments. Approximately one-half of the subjects for each experiment had previously participated in aircraft-noise-related experiments. Ninety-six subjects participated in the experiment judging the outdoor noises, and thirty-two subjects participated in the indoor-noise experiment. No subject participated in both sets of experiments described in this report.

All test subjects were given audiograms prior to the experiments to verify normal hearing within 20 dB (ANSI 1969). Table II gives the sex and age data for the two sets of subjects.

Reproduction System and Test Facilities

Audio reproduction system.- A diagram of the basic noise reproduction system is shown in figure 3. The monophonic recordings of the aircraft noise stimuli were played back on a studio-quality tape recorder. A commercially available noise-reduction system which provided a nominal 30-dB increase in signal-to-noise ratio above normal tape recorders was used to reduce tape hiss to inaudible levels between stimuli. Although some hiss was audible on the original recordings from which the presentation recordings were made, the noise-reduction system prevented an increase of relative hiss for the lower stimuli levels. Therefore, a nearly constant peak stimulus to hiss ratio of 50 dB (A-weighted) was maintained across stimulus type and level. A one-third-octave band equalizer was used to compensate for the frequency response in the indoor- and the outdoor-test facilities; separate amplification and loudspeaker reproduction systems were used in both facilities.

Outdoor-simulation facility.- The exterior effects room (EER) of the Langley aircraft noise reduction laboratory at NASA Langley Research Center was used in the outdoor-acoustic-simulation experiment. This room has seating for 39 subjects and a volume of approximately 340 m^3. The reverberation time for the room was approximately 0.5 sec at 1000 Hz. The stimuli were presented by means of six overhead loudspeakers. The subject seating locations used for this set of tests are shown in figure 4. As previously mentioned, a one-third-octave band equalizer was used to compensate for the frequency response of the facility. The response of the outdoor-simulation facility after equalization is shown in figure 5. The shaded area for each one-third-octave band shows the range of measurements made at the subject head locations (no subjects present) for all seats used when pink noise was applied to the equalizer input.

Indoor-simulation facility.- The interior effects room (IER) of the Langley aircraft noise reduction laboratory was used in the indoor-acoustic-simulation experiment. This room was configured as a typical living room with a volume of approximately 42 m^3. The stimuli were presented by means of four loudspeakers located outside and above the room. The subject seating locations for this set of tests are shown in figure 6.

The construction of the room was typical of those for similarly constructed houses (ref. 5). In order to provide a more standardized simulation of attenuation through the structure, a one-third-octave band equalizer was used to modify the response for closer agreement with the average transmission loss data presented in reference 5. The relative transmission loss, after equalization, is shown in figure 7. The shaded area for each one-third-octave band represents the range of measurements for the four subject positions in the room. The circle symbols are the average transmission loss data presented in reference 5. The range of data from the measurements in the IER has been normalized for comparison with the referenced standard data.

Experimental Design

Numerical category scaling was chosen as the psychophysical method for the experiments described in this report. This choice was made primarily to conserve test time and allow each test subject to make as many judgments as possible in a given single trip to the laboratory. The scale selected was the unipolar, 10 point scale, "0 to 9." The end points of the scale were labeled "Not Noisy at All" and "Extremely Noisy." The label "Noisy" was chosen to imply the unwanted, unpleasant, or objectionable characteristics of the sounds.

Four tape recordings of the various stimuli were prepared for presentation to the subjects. The orders of the stimuli on the recordings are given in table III. Tapes I and IV contained all 60 different stimuli (6 aircraft, takeoffs and landings, 5 levels of stimulus). The particular orders were based on random selection with two constraints to provide some measure of balance. The first was that no particular type of noise stimulus would occur more than three times in any one tape. The second constraint was that each of the five levels would occur once in succeeding groups of five stimuli, starting at the beginning of a tape. Tapes III and IV contained the same stimuli as tapes I and II, but in reverse order. Each tape recording required 30 min for playback and served as a test session for the subjects. A period of 5 sec was provided between stimuli for the subjects to make and record their judgments.

The subjects used in the outdoor-simulation experiment were assigned to 16 groups of 6 subjects each. Those for the indoor-simulation experiment were assigned to 8 groups of 4 subjects. Each of the groups was assigned to a particular presentation order of the four tape recordings, as shown in table IV. This was done to provide a balance in presentation to prevent subject fatigue or other temporal effects from unduly influencing the results.

Procedure

Upon arrival at the laboratory, the subject groups were seated in a conference room and given a sheet of instructions for the subsequent tests. A copy of this instruction sheet is given in the appendix. After reading the instruction sheets, the subjects completed two consent forms required of all subjects who participate in subjective experiments in the laboratory. Copies of these forms are given in the appendix. The subjects were then given a copy of the scoring sheets used for the tests (see appendix), given a brief verbal explanation of the scoring sheets, and asked by the test conductor if they had any questions concerning the tests. The same person served as the test conductor throughout both experiments.

The subjects were then ushered by the test conductor to the appropriate test facility, allowed to make their own choice of the available seats, and assigned a subject number. A demonstration of three flyover sounds was given while the test conductor remained in the test facility. The subjects were instructed to make mental judgments of the demonstration sounds to gain practice in scoring the sounds they were to hear during the tests. The test conductor again asked if there were any questions concerning the tests and left the test facility. The first test session then began. The test conductor reentered the test facility at the conclusion of each 30-min session, collected the completed scoring sheets, and issued new sheets for the next session. The subjects were given a 15-min rest period between the second and third sessions.

RESULTS AND DISCUSSION

The following sections of this report describe the analyses and discuss results obtained from the two related subjective experiments, which investigated the ability of the different rating scales to predict or quantify the noisiness of the aircraft noise stimuli. In addition, analyses were performed to examine the possibility of differences in the stimuli which could have affected the manner in which the subjects made their judgments. In the first three sections, the reduction of acoustic and subjective data is examined and the analyses used to relate the two sets of data are presented. In the section "Predictive Ability of Rating Scales," these relationships are used to examine the predictive ability of the various rating scales which quantify the noisiness of all the stimuli as a group. In the final section, how the subjects judged the individual stimuli is considered, and the results of the two experiments are compared.

Acoustic Data Reduction

Outdoor experiment.- Two different acoustic analysis techniques were used to determine the levels of the stimuli in terms of several of the more common physical rating scales. A precision sound level meter and graphic level recorder were used to determine the time histories of L_{A1} and L_{D1} for each stimulus. The frequency range for this analysis was 22.5 Hz to 22.5 kHz, and "slow" time averaging was used. From this analysis the peak value for each stimulus and rating scale was obtained, as well as the time the level exceeded the peak minus 10 dB for the scale. Real-time one-third-octave band analysis (analog filtering with digital sampling, root-mean-square detection, and integration) was used to provide time histories for computer analyses of the stimulus in terms of the other rating scales. For this analysis, the center frequencies of the one-third-octave bands ranged from 50 Hz to 10 kHz and the integration time was 0.5 sec.

For both analyses the stimuli were measured in the outdoor-simulation facility at the head position of the first row, middle subject (see fig. 4), with no subjects present. This particular location was also used in determining the equalization necessary for the facility and thereby represents the location with the best response to pink noise. The measured physical levels are given in table I for each stimulus at its highest presentation level. The differences between L_{A1} and L_{A2} and between L_{D1} and L_{D2} result from the differences in time averaging methods and frequency range of analysis for the two analysis techniques.

Indoor experiment.- The primary acoustical analysis for the indoor experiment used a sound level meter and graphic level recorder to obtain time histories of L_{A1} and L_{D1}. The peak values from the analysis are given in table V. It was also desirable to compare the subjective results of the experiment with the outdoor levels which would produce the levels measured indoors. In order to do this, the following procedures were used. As mentioned in the previous section, one-third-octave band sound pressure levels were measured for the outdoor experiment and stored in digital form for computer analysis. It was assumed that the average attenuation (A-weighted) afforded by a typical house was 20 dB. (See ref. 5.) A level shift, constant in both time and frequency, was applied to these one-third-octave band data to raise the A-weighted levels to the appropriate average value. The shifted one-third-octave band data were reanalyzed by computer to provide the outdoor levels in terms of the other rating scales. The measured and estimated levels determined by this procedure are given in table V.

Subjective Data Reduction

The mean values, over subjects and repeats, of the judgments were calculated for each stimulus type and level for the outdoor and the indoor experiments. An example is given in figure 8, where the mean subjective judgments for the outdoor experiment for the five levels of the Concorde takeoff noise are plotted against L_{A1}. The curved line represents a hand fit through the data points. As can be seen, the relationship is not linear at either the upper or lower end of the subjective scale. This type of nonlinearity resulted from the fact that the judgments for the stimuli near the ends of the subjective scale tend to deviate significantly from a normal distribution. In order to reduce the effect of these nonlinearities, which for some stimuli were more severe than those shown in figure 8, the data were subsequently analyzed by using the method of successive intervals. This method does not require the assumption of normality and is classified a "special case of the law of categorical judgment" in reference 6. The analysis used was based on an iterative least-squares method developed in reference 7. The estimated scale values determined by this procedure for each stimulus were normalized in the form of unit normal deviates based on all judgments for a given experiment. The values thusly determined for the Concorde takeoff stimuli are shown in figure 9. The origin of the estimated and normalized scale axis now represents the median value of all judgments (all stimuli and all subjects) for the outdoor experiment. In comparing figure 9 with figure 8, it can be seen that the successive interval procedure did remove nonlinear end effects and allowed the use of linear regression analysis to compare the subjective results and the objective measurements. From the appropriate regression equations for each of the objective rating scales, the values which predicted an estimated subjective judgment of zero were found for each stimulus type. These values are designated ENL, which is defined as "equal noisiness level." A graphical example of this procedure is shown in figure 9. The solid line represents the best linear fit to the set of estimated scale values for the Concorde takeoff noise stimuli for the outdoor experiment. The location on the objective scale axis of the vertical dashed line intersecting the regression line at the origin of the subjective scale thereby represents the ENL of the Concorde takeoff stimuli in terms of L_{A1}.

Reliability of Subjective Judgments

In both the outdoor- and the indoor-simulation experiments, all subjects judged each stimulus (aircraft type and level) twice. Regression analyses were performed on these repeated judgments in two ways, the results of which are given in table VI. The first was a regression of each individual subject's second judgment (dependent variable) on his first judgment (independent variable) for each stimulus. The second was a regression of the mean (over subjects) of the second judgments on the first judgments for each of the 60 stimuli. The results shown for both experiments and both types of regression indicate that the subjective judgments were highly reliable. For individual judgments, about 74 percent of the total second-judgment variance was explained by the regressions. The higher values of the intercept and the lower values for the slope for the individual judgments as compared with those for mean judgments were primarily a result of the limited range of the scale used. For the regressions on the means for each stimulus, about 98 percent of the second-judgment variance was explained by the regressions.

Predictive Ability of Rating Scales

Various linear regression analyses were performed on the subjective data with values of several different rating scales as independent variables. In the following discussions on the applicability of these scales to predict the noisiness of the Concorde and other aircraft sounds, the estimated subjective scale values from the method of successive intervals were grouped and regressions were performed in two different ways. For the first, each stimulus type (aircraft type and operation) was considered independently for the regressions by using the different rating scales. From these regressions, the values of ENL were obtained for each stimulus type, as graphically described in figure 9. For the second type of regressions, all stimulus types were included in the analysis for each rating scale. The corresponding intercepts, slopes, and correlation coefficients were determined. The primary results of these analyses for the two sets of experiments follow.

Outdoor experiment.- Table VII presents the ENL values and results of the regression analyses for all stimuli for the different rating scale investigated. The range and standard deviations of the ENL values for each rating scale are also presented. In examining these results, each scale was rank ordered in three different ways. The first was based on minimum standard deviation of ENL, the second on minimum range of ENL, and the third on maximum correlation coefficient. These results are shown in table VIII. Although the differences between the correlation coefficients for the different rating scales could not be shown to be highly significant because of the high correlation between rating scales, a trend was established and was reinforced by the ranking based on standard deviation and range of the ENL values. The most applicable group of rating scales consisted of the first five in all three ranking schemes, that is, L_{A1}, L_{A2}, EPL, PL, and EPNL. The next group of somewhat less applicability was L_{D1}, PNL, and L_{D2}. The performance of tone corrected perceived noise level PNLT was not as good as the previous two groups.

These results concerning PNLT and similar results previously found in several studies (refs. 2, 8, and 9) indicate that either tone corrections are not necessary or that the manner in which they are calculated is inadequate. Several indications which resulted from the acoustical analyses, as compared with listening to the recorded noises, tend to suggest that the manner of calculation is inadequate. It was obvious upon listening to the Concorde takeoff noise that no tonal components were audible. However, a 1.2-dB tone correction was added by the PNLT procedure. Closer examination of the one-third-octave band analyses and 1/2-sec time histories revealed that tone corrections ranging from 0.0 to 2.4 dB occurred randomly in both time and frequency of the one-third-octave bands between 500 Hz and 1000 Hz. It can only be supposed that the high band levels causing the tone corrections were the result of the distortion-like crackling sounds characteristic of high exhaust velocity turbojet engines. The randomness of tone corrections was not nearly so evident in the noise of aircraft with true tonal qualities, for example, the DC-8 turbofan landing noise.

It is of interest to note the rather good performance of the scales based on Stevens Mark VII perceived level calculations, that is, PL and EPL. The perceived level scale (ref. 10) was an attempt to establish a link between the earlier loudness calculation procedures and the slightly different noisiness calculation procedures. One somewhat unusual aspect of the PL calculation procedure is that a doubling of the subjective attribute, loudness or noisiness, is equated to a 9-dB perceived level difference instead of the 10-dB difference previously used. This is evidenced by the higher values for the slopes shown in table VII for the rating scales PL and EPL.

Indoor experiment.- Table IX presents equal noisiness levels, their range and standard deviations, and regression-analyses results for the indoor-simulation experiment, in the same manner as for the outdoor-simulation experiment. An examination of these data reveals a somewhat surprising result in that the performance of the rating scales based on estimated outdoor levels was equally as good as, if not superior to, the performance of the scales based on actual indoor measurements. The rank ordering of the rating scales as measured indoors is obvious from table IX, L_{A1} being consistently superior to L_{D1}. The rank ordering of the rating scales based on the estimated outdoor levels is presented in table X. Although there was some variation in the orders within groups, the same groups were formed as in the outdoor-simulation experiment. The first group contained the rating scales EPL, L_{A1}, L_{A2}, PL, and EPNL. The second group consisted of L_{D1}, PNL, and L_{D2}. The tone corrected perceived noise level PNLT ended up alone as the third group.

Although it was not surprising that the estimated outdoor levels were highly correlated with the indoor judgments (ref. 9), it was surprising that these correlations were as high as, if not higher than, those between the actual indoor levels and the judgments. Because of this result and the fact that environmental noise is most commonly measured out of doors, results of the indoor experiment are presented in terms of the estimated outdoor levels.

Effects of noise duration.- The aircraft flyover noises used in these experiments varied widely in duration, as shown in figure 1. In order to examine whether or not these different durations produced any systematic effects on the calculated ENL values for the outdoor experiment, regression analyses were performed on the ENL values for the L_{A1} and PNL rating scales. Two different forms of duration corrections were used as the independent variable. The first, an estimated correction, was based solely on the total time between the first and last excursion of the noise level above the peak level minus 10 dB. The second type of correction was that prescribed in the EPNL calculation procedure (ref. 4) and was determined by integrating the levels over the time limits.

The results of these regressions are given in table XI in terms of several parameters. By applying the results of the regressions, the standard deviations in the equal noisiness levels shown in table VII have been reduced. The highest correlation was found for the PNL rating scale with the integrated duration correction. The slope from this regression is equivalent to a 2.18 dB per doubling of the effective duration. Figure 10 presents the equal noisiness levels in terms of PNL as a function of the effective duration which was determined from the integrated duration corrections for each stimulus. The solid line represents the 2.18 dB per doubling of duration determined from the regression, whereas the dashed line represents the 3 dB per doubling used in EPNL calculations.

From the fact that different duration corrections were obtained for the two rating scales used in the example, it is obvious that other unknown factors are confounded with duration within the rating scales for the different stimuli. The only solution for determining the true nature of duration effects would be to hold all other variables within the stimuli fixed while only duration was varied. This approach is impractical, if not impossible, when recordings of aircraft flyover noises are used as stimuli.

Relative Noisiness of Stimuli

The applicability of subjective acoustic results obtained in laboratory studies is always difficult to assess for the real-life or community situation. The results reported herein are no exception. The stimuli used in the study could not possibly cover the wide range of levels and duration which exist in the airport community. In the present study, one location was selected for each operation, that is, the measurement locations for FAR 36 aircraft noise certification (ref. 11) for takeoff and landing. This study was also limited as to the maximum level at which the aircraft noise stimuli could be reproduced, both from the standpoint of high quality physical reproduction capabilities and because of safety considerations for the test subjects. For these reasons, a form of relative rather than absolute response was asked of the subjects. The remaining sections of this report compare the judgments of Concorde stimuli with those of the other aircraft stimuli.

It has been shown in the previous sections that little significance can be placed on the differences in general applicability between most of the various rating scales. Because of this, and because of the widespread use of the rating scales L_{A1} and EPNL, the remaining results and discussions are presented only in terms of the two scales L_{A1} and EPNL measured out of doors.

Noisiness comparison between Concorde and the group of other aircraft.- Before comparing the noisiness of the Concorde stimuli with other individual aircraft noise stimuli, it was appropriate to first consider the other stimuli as a group. Tables VII and IX show that the ENL values determined for each of the different stimuli, in terms of any given rating scale, were, in general, different from any of the other stimuli for the same rating scale. The analysis to follow was performed to determine whether subjective judgments made of the Concorde stimuli were significantly different from those made of the other stimuli considered collectively.

The present analysis was based on an analysis-of-covariance method described in reference 12. Linear least-squares regression analyses were performed with the estimated subjective scale values for each type and level of the stimuli as the dependent variable and the corresponding measured rating scale values (L_{A1} and EPNL) as the independent variable, using three different models. The first model assumed a common slope and common mean for all stimuli. The second model assumed a common slope but separate means for the Concorde stimuli and the group of other aircraft stimuli. The third model assumed separate slopes and separate means. Details for this analysis can be found in reference 12 and basically consisted of comparing the residual mean squares between the three models with appropriate F-tests. First a null hypothesis of common slope was tested by comparing the second and third models. Failure to reject the null hypothesis of common slope led to a further test of the null hypothesis of common adjusted means, assuming common slope by comparing the first and second models. This type of analysis was performed for both experiments by using both rating scales, L_{A1} and EPNL, and by considering takeoff and landing stimuli together and separately. The results of the analysis in terms of calculated and tabulated F-values are presented in table XII.

As shown, in none of the cases can the null hypothesis of common slope be rejected at the 1-percent level. If the less stringent significance level of 5 percent were chosen, it would be possible to reject the null hypothesis for the combined takeoff and landing results for rating scale EPNL in both experiments. However, even at the 5-percent level, common slope could be rejected for neither takeoff nor landing conditions. Therefore, it is felt that the significance level should not be relaxed for this particular case. As a result of this analysis, there is not sufficient justification to reject the common slope null hypothesis.

Under the assumption then of common slope, the tests for differences in adjusted group means were performed. As shown, no significant differences were found for rating scale L_{A1} when takeoff and landings were considered together. However, a significant difference was found for landing operations in the outdoor experiment.

In terms of the rating scale, EPNL significant differences were found in the adjusted means between the Concorde stimuli and all of the other aircraft stimuli when takeoffs and landings were considered together for both the outdoor and the indoor experiments. Significant differences were also found when considering only takeoff noises for both experiments; however, in the case of landing noises, the greater variability within the group of all aircraft except Concorde prevented the determination of such a difference.

Based on the preceding analysis for takeoff and landing noises together in the outdoor situation, the EPNL rating scale was found to underestimate the noisiness of Concorde noise by 3.5 dB as compared with the noisiness of the group of other aircraft noises with widely varying temporal and spectral characteristics. For landing noises only, again in the outdoor situation, the rating scale L_{A1} was found to overestimate the noisiness of Concorde noise by 3.2 dB as compared with the noisiness of the group of other aircraft.

Equal noisiness levels in outdoor experiment.- Table VII presented the ENL values for each stimulus from the regression analyses of the subjective scale values on the various physical or rating scales. The results for the rating scales L_{A1} and EPNL are graphically represented in figures 11(a) and 11(b), respectively. In both figures, the ENL values are plotted in descending order from left to right with the stimuli separated into takeoff and landing operations. For those stimuli which lie below the mean value, indicated by the arrow along the ENL scale, the rating scale underestimates the relative noisiness of the stimuli. It is estimated that the accuracy of the subjective equal noisiness levels is typically as good as the accuracy of the physical measurements; consequently, a difference between the equal noisiness levels of two stimuli greater than 1 dB would be statistically significant. From figure 11(a) it can be seen that L_{A1} predicted the relative noisiness of Concorde takeoff noise very well, whereas L_{A1} overestimated the

Concorde landing noise by about 3 dB. A somewhat different result occurred, however, for EPNL. Figure 11(b) shows that the noisiness of both the takeoff and landing noise of Concorde was underestimated by about 3 dB.

Equal noisiness levels in indoor experiment.- The results of the ENL calculations for the indoor experiment are shown in figures 12(a) and 12(b) for the rating scales L_{A1} and EPNL, respectively, from the estimated outdoor levels. Again, the results have been separated into takeoff and landing cases and rank ordered in decreasing ENL within the cases. Similar conclusions concerning the relative noisiness of Concorde can be made as were made in the outdoor experiment. In terms of L_{A1}, Concorde takeoff noise was judged very near the mean, whereas the Concorde landing noise was overestimated approximately 3 dB. In terms of EPNL, both the takeoff and landing noises of Concorde were underestimated by approximately 3 dB.

Comparison of outdoor and indoor experiments.- A comparison of figure 11(a) with figure 12(a) and figure 11(b) with figure 12(b) shows that a remarkable similarity existed between the ENL values for the outdoor and the indoor experiments. For each aircraft type, noise level, and operation, the linear regression of the estimated subjective values from the indoor experiment was performed on those from the outdoor experiment. These analyses of the 60 stimuli data points resulted in a correlation coefficient of 0.993. This value is extremely high considering that the estimated subjective values for the two experiments were based on two different groups of subjects. Further examination of the effects of this high correlation on the ENL values for the different aircraft types was carried out by performing regressions with the ENL values of the indoor-simulation experiment (estimated outdoor levels) as the dependent variable and with the corresponding ENL values of the outdoor experiment as the independent variable. The results of the analyses are given in table XIII. As shown, both the correlation coefficient and slope were greater for EPNL than for L_{A1}. The analysis of variance table for the regressions is included to indicate why the correlation for EPNL was much higher than for L_{A1}. The total sum of squares for EPNL was much larger than for L_{A1}, while the residual was somewhat smaller. This greater total sum of squares is also evidenced by the larger range in ENL values for EPNL, shown in figure 12(b), than for L_{A1}, shown in figure 12(a). It should also be noted that the slope for EPNL was greater than the near unity value for L_{A1}. One possible implication from these results is that, if a systematic source of error was inherent in the EPNL calculation, this error was also affected by the transfer characteristics of the indoor situation. One obvious characteristic was the transmission loss of the wall structure as a function of frequency. An examination of the changes in ENL values in terms of EPNL resulting from the change in listener or test-subject location from the outdoor situation to the indoor situation is shown in figure 13. These results were obtained by first subtracting the mean ENL value from the ENL value of each stimulus to arrive at the relative ENL values for each experiment. The relative ENL values of the outdoor-simulation experiment were then subtracted from those of the indoor-simulation experiment. A close examination of the one-third-octave band spectra of figure 2 and comparison of the results in figure 13 revealed that in general those stimuli with strong high-frequency tonal components experienced the larger positive changes in ENL values, that is, a greater overestimation in noisiness. Those stimuli with greater low-frequency one-third-octave band components, particularly the DC-8 turbojet landing, experienced the larger negative changes in ENL values, that is, a greater underestimation in noisiness. The combination of these results, along with general trends of the ENL values of figure 11(b) and the regression results from table VII for the tone corrected perceived noise level, gives further evidence that the tone correction procedures did nothing to improve and, in general, reduced the predictive capabilities of EPNL.

CONCLUSIONS

A set of laboratory subjective listening tests were performed to investigate the relative noisiness of recorded supersonic-transport noises and recorded noises of five other commercial aircraft. All of the recordings were made at locations very near either the takeoff or landing locations of FAR 36 certification. Ninety-six test subjects made noisiness judgments on a total of 120 stimuli in an outdoor-acoustic simulation. Thirty-two different subjects made similar judgments in an indoor-acoustic simulation. All judgments were made by using the numerical-category-scaling technique. The following conclusions were noted:

1. The effective perceived noise level (EPNL) of FAR 36 procedure was found to underestimate the noisiness of the supersonic-transport noises by approximately 3.5 dB as compared with the noisiness of the group of other aircraft noises.

2. The peak A-weighted rating scale was found to overestimate the noisiness of the supersonic-transport landing noise by approximately 3.2 dB as compared with the noisiness of the group of other aircraft noises. No significant differences were found between the noisiness of the supersonic-transport takeoff noise and the group of other aircraft noises using the A-weighted scale.

3. A very high correlation was found between the subjective results of the indoor-simulation experiment and those of the outdoor-simulation experiment.

4. The rating scales found to be most consistent in predicting the noisiness for all aircraft were as follows: A-weighted scale obtained by two methods, Stevens Mark VII perceived level procedure with and without duration corrections, and the EPNL of FAR 36 procedure. These were followed by a group of somewhat less consistent scales which included the perceived-noise-level (PNL) calculation procedure and D-weighted scale obtained by two different methods. The PNL with tone corrections by the FAR 36 method was found to be the least consistent of the rating scales investigated.

5. A correction of approximately 2 dB per doubling of effective duration was found to be most applicable for increasing the accuracy of the PNL rating scale.

Langley Research Center
National Aeronautics and Space Administration
Hampton, VA 23665
March 9, 1977

APPENDIX

INSTRUCTIONS, CONSENT FORMS, AND SCORING SHEET

Copies of the instructions, consent forms, and scoring sheet, which were used in the outdoor- and the indoor-simulation experiments, are presented in the following pages.

APPENDIX

INSTRUCTIONS

The experiment in which you are participating is to help us understand the characteristics of aircraft sounds which can cause annoyance in airport communities. We would like you to judge how NOISY some of these aircraft sounds are. By NOISY we mean--UNWANTED, OBJECTIONABLE, DISTURBING, or UNPLEASANT.

The test today is divided into four sessions of approximately 30 minutes duration, and each session contains 30 sounds. A scoring sheet will be provided for each session and will contain scales for your judgment of each sound. Your judgments are to be made by circling one of the numbers on the appropriate scale. Each scale is numbered from "0"--NOT NOISY AT ALL to "9"--EXTREMELY NOISY. If you judge a sound to be very noisy, you should circle a number closer to the EXTREMELY NOISY end of the scale. Similarly, if you judge the sound to be slightly noisy, you should circle a number closer to the NOT NOISY AT ALL end of the scale. There are neither right nor wrong answers; all we want is your own judgment of each sound.

In order to familiarize you with judging the aircraft sounds, we will play three aircraft sounds before we begin the first session. You may practice making judgments for these three sounds by using the scoring sheet provided. I will remain with you in the testing room during this practice time to answer any questions you may have.

Thank you for helping us with these tests.

APPENDIX

VOLUNTARY CONSENT FORM FOR SUBJECTS FOR HUMAN RESPONSE TO AIRCRAFT NOISE AND VIBRATION

I understand the purpose of the research and the technique to be used, including my participation in the research, as explained to me by the Principal Investigator (or qualified designee).

I do voluntarily consent to participate as a subject in the human response to aircraft noise experiment to be conducted at NASA Langley Research Center on ________________________.
Date

I understand that I may at any time withdraw from the experiment and that I am under no obligation to give reasons for withdrawal or to attend again for experimentation.

I undertake to obey the regulations of the laboratory and instructions of the Principal Investigator regarding safety, subject only to my right to withdraw declared above.

I affirm that, to my knowledge, my state of health has not changed since the time at which I completed and signed the medical report form required for my participation as a test subject.

____
Signature of Subject

APPENDIX

VOLUNTARY CONSENT FORM FOR RECORDING OF SUBJECTS RESPONSE

TO AIRCRAFT NOISE AND VIBRATION

I understand that AUDIO/VIDEO recordings are to be made of my response to the AIRCRAFT NOISE AND/OR VIBRATION experiment to be conducted at NASA Langley Research Center on ______________________, and that these recordings are to be held in strictest confidence.

I have been informed of the purpose of such recordings and do voluntarily consent to their use.

I further understand that I may withdraw my approval of such recordings at any time before or during the actual recording.

____

Signature of Subject

APPENDIX

SCORING SHEET

NAME ____________________ SESSION __________ TAPE __________

SOUND		JUDGMENT	
1	NOT NOISY AT ALL	0 1 2 3 4 5 6 7 8 9	EXTREMELY NOISY
2	NOT NOISY AT ALL	0 1 2 3 4 5 6 7 8 9	EXTREMELY NOISY
3	NOT NOISY AT ALL	0 1 2 3 4 5 6 7 8 9	EXTREMELY NOISY
4	NOT NOISY AT ALL	0 1 2 3 4 5 6 7 8 9	EXTREMELY NOISY
5	NOT NOISY AT ALL	0 1 2 3 4 5 6 7 8 9	EXTREMELY NOISY
6	NOT NOISY AT ALL	0 1 2 3 4 5 6 7 8 9	EXTREMELY NOISY
7	NOT NOISY AT ALL	0 1 2 3 4 5 6 7 8 9	EXTREMELY NOISY
8	NOT NOISY AT ALL	0 1 2 3 4 5 6 7 8 9	EXTREMELY NOISY
9	NOT NOISY AT ALL	0 1 2 3 4 5 6 7 8 9	EXTREMELY NOISY
10	NOT NOISY AT ALL	0 1 2 3 4 5 6 7 8 9	EXTREMELY NOISY
11	NOT NOISY AT ALL	0 1 2 3 4 5 6 7 8 9	EXTREMELY NOISY
12	NOT NOISY AT ALL	0 1 2 3 4 5 6 7 8 9	EXTREMELY NOISY
13	NOT NOISY AT ALL	0 1 2 3 4 5 6 7 8 9	EXTREMELY NOISY
14	NOT NOISY AT ALL	0 1 2 3 4 5 6 7 8 9	EXTREMELY NOISY
15	NOT NOISY AT ALL	0 1 2 3 4 5 6 7 8 9	EXTREMELY NOISY
16	NOT NOISY AT ALL	0 1 2 3 4 5 6 7 8 9	EXTREMELY NOISY
17	NOT NOISY AT ALL	0 1 2 3 4 5 6 7 8 9	EXTREMELY NOISY
18	NOT NOISY AT ALL	0 1 2 3 4 5 6 7 8 9	EXTREMELY NOISY
19	NOT NOISY AT ALL	0 1 2 3 4 5 6 7 8 9	EXTREMELY NOISY
20	NOT NOISY AT ALL	0 1 2 3 4 5 6 7 8 9	EXTREMELY NOISY
21	NOT NOISY AT ALL	0 1 2 3 4 5 6 7 8 9	EXTREMELY NOISY
22	NOT NOISY AT ALL	0 1 2 3 4 5 6 7 8 9	EXTREMELY NOISY
23	NOT NOISY AT ALL	0 1 2 3 4 5 6 7 8 9	EXTREMELY NOISY
24	NOT NOISY AT ALL	0 1 2 3 4 5 6 7 8 9	EXTREMELY NOISY
25	NOT NOISY AT ALL	0 1 2 3 4 5 6 7 8 9	EXTREMELY NOISY
26	NOT NOISY AT ALL	0 1 2 3 4 5 6 7 8 9	EXTREMELY NOISY
27	NOT NOISY AT ALL	0 1 2 3 4 5 6 7 8 9	EXTREMELY NOISY
28	NOT NOISY AT ALL	0 1 2 3 4 5 6 7 8 9	EXTREMELY NOISY
29	NOT NOISY AT ALL	0 1 2 3 4 5 6 7 8 9	EXTREMELY NOISY
30	NOT NOISY AT ALL	0 1 2 3 4 5 6 7 8 9	EXTREMELY NOISY

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TABLE I.- MAXIMUM NOISE LEVELS FOR OUTDOOR AND INDOOR EXPERIMENTS

Aircraft	Operation	Outdoor experiment									Indoor experiment	
		L_{A1}	L_{A2}	L_{D1}	L_{D2}	PNL	PNLT	EPNL	PL	EPL	L_{A1}	L_{D1}
Concorde	Takeoff	89.8	90.3	94.5	95.2	101.9	103.1	100.4	92.3	90.0	78.2	83.0
	Landing	91.3	91.5	96.5	97.0	103.8	104.4	98.3	94.9	88.1	79.3	84.0
B-747	Takeoff	90.5	91.0	95.5	96.8	103.6	104.9	106.1	94.4	95.9	79.5	86.2
	Landing	89.3	89.9	94.3	95.6	102.6	104.8	103.0	92.4	91.6	79.2	84.2
B-737	Takeoff	92.3	93.1	97.0	99.2	105.7	107.6	106.1	96.5	95.9	81.6	87.1
	Landing	88.8	90.3	94.8	97.6	104.7	109.0	103.1	94.1	90.7	76.5	83.3
DC-8 TF	Takeoff	91.8	92.6	96.0	97.2	103.5	106.3	108.0	94.7	97.4	80.5	86.2
	Landing	87.8	88.2	96.0	97.3	103.1	107.3	102.3	92.1	88.1	73.6	81.8
DC-8 TJ	Takeoff	91.3	91.7	96.3	96.9	103.6	104.7	105.1	93.8	94.3	80.2	85.8
	Landing	90.0	90.7	95.0	95.8	103.2	104.4	102.7	93.8	92.3	79.0	85.0
CV-640	Takeoff	89.8	90.1	96.3	97.1	103.7	106.1	101.9	94.4	90.9	84.0	91.2
	Landing	85.5	87.4	95.5	97.1	102.7	107.2	99.1	92.2	84.9	72.5	82.5

TABLE II.- TEST SUBJECTS

Sex	Number of participants	Mean age	Median age	Age range
Outdoor experiment				
Male	16	27	22	18 to 54
Female	80	35	34	19 to 61
Indoor experiment				
Male	4	26	22	21 to 39
Female	28	39	37	23 to 59

TABLE III.- PRESENTATION ORDER OF STIMULI ON TAPE RECORDINGS

Tape I	Tape II	Tape III	Tape IV
A-1	E-2	J-2	B-4
B-2	B-5	I-1	L-1
K-5	F-4	G-5	K-3
L-3	C-3	K-4	J-5
C-4	D-1	H-3	A-2
H-2	I-3	B-3	D-5
F-3	J-1	D-2	G-2
G-1	H-5	E-4	E-3
I-4	L-4	C-1	H-4
E-5	K-2	A-5	F-1
A-3	G-4	I-2	A-4
D-4	F-2	H-1	K-1
C-2	E-1	G-3	L-2
L-5	C-5	F-5	J-3
B-1	D-3	J-4	I-5
J-4	I-5	B-1	D-3
F-5	J-3	L-5	C-5
G-3	L-2	C-2	E-1
H-1	K-1	D-4	F-2
I-2	A-4	A-3	G-4
A-5	F-1	E-5	K-2
C-1	H-4	I-4	L-4
E-4	E-3	G-1	H-5
D-2	G-2	F-3	J-1
B-3	D-5	H-2	I-3
H-3	A-2	C-4	D-1
K-4	J-5	L-3	C-3
G-5	K-3	K-5	F-4
I-1	L-1	B-2	B-5
J-2	B-4	A-1	E-2

Aircraft stimuli key:

A - B-737 takeoff
B - DC-8 TF landing
C - Concorde takeoff
D - CV-640 landing
E - B-747 landing
F - CV-640 takeoff
G - DC-8 TF takeoff
H - DC-8 TJ landing
I - Concorde landing
J - B-747 takeoff
K - B-737 landing
L - DC-8 TJ takeoff

Stimuli levels:

1 to 5 in increasing level

TABLE IV.- ORDER OF TAPES PRESENTED TO TEST-SUBJECT GROUPS

Test-subject group (a)	Tape recording for -				Time
	Presentation 1	Presentation 2	Presentation 3	Presentation 4	
1	I	II	III	IV	a.m.
2	I	IV	III	II	p.m.
3	II	I	IV	III	a.m.
4	II	III	IV	I	p.m.
5	III	IV	I	II	a.m.
6	III	II	I	IV	p.m.
7	IV	III	II	I	a.m.
8	IV	I	II	III	p.m.
9	IV	I	II	III	a.m.
10	IV	III	II	I	p.m.
11	III	II	I	IV	a.m.
12	III	IV	I	II	p.m.
13	II	III	IV	I	a.m.
14	II	I	IV	III	p.m.
15	I	IV	III	II	a.m.
16	I	II	III	IV	p.m.

[a]Only subject groups 1 to 8 were used in indoor experiment.

TABLE V.- MAXIMUM MEASURED INDOOR LEVELS AND ESTIMATED OUTDOOR LEVELS

FOR INDOOR EXPERIMENT

Aircraft	Operation	Measured indoor levels		Estimated outdoor levels								
		L_{A1}	L_{D1}	L_{A1}	L_{A2}	L_{D1}	L_{D2}	PNL	PNLT	EPNL	PL	EPL
Concorde	Takeoff	78.2	83.0	97.8	98.3	102.5	103.2	110.0	111.2	108.5	100.3	97.9
	Landing	79.3	84.0	99.3	98.5	104.5	105.0	111.9	112.4	106.4	102.0	96.1
B-747	Takeoff	79.5	86.2	98.5	99.0	103.5	104.8	111.7	113.0	115.3	102.6	104.1
	Landing	79.2	84.2	97.3	97.9	102.3	103.6	110.7	112.9	111.1	100.3	99.3
B-737	Takeoff	81.6	87.1	100.3	101.1	105.0	107.3	113.8	115.7	114.2	104.9	104.0
	Landing	76.5	83.3	96.8	98.3	102.8	105.6	112.8	117.1	111.2	102.4	98.3
DC-8 TF	Takeoff	80.5	86.2	99.8	100.6	104.0	105.2	111.6	114.4	116.2	102.8	105.5
	Landing	73.6	81.8	95.8	96.2	104.0	104.5	111.2	115.4	110.4	100.3	96.0
DC-8 TJ	Takeoff	80.2	85.8	99.3	99.7	104.3	104.9	111.7	112.8	113.2	101.7	101.9
	Landing	79.0	85.0	98.0	98.7	103.0	103.8	111.4	112.6	110.2	101.9	100.2
CV-640	Takeoff	84.0	91.2	97.8	98.1	104.3	105.1	111.8	114.2	109.2	102.7	99.1
	Landing	72.5	82.5	93.5	95.4	103.5	105.1	110.8	115.3	107.2	100.5	93.1

TABLE VI.- REGRESSION ANALYSES FOR REPEATED JUDGMENTS

Regression	Intercept	Slope	Correlation coefficient
Outdoor experiment			
Individual judgments	0.815	0.845	0.856
Means over subjects	.172	.987	.997
Indoor experiment			
Individual judgments	0.699	0.867	0.865
Means over subjects	.190	.986	.992

TABLE VII.- EQUAL NOISINESS LEVELS AND REGRESSION ANALYSES FOR OUTDOOR EXPERIMENT

Aircraft	Operation	L_{A1}	L_{A2}	L_{D1}	L_{D2}	PNL	PNLT	EPNL	PL	EPL
Equal noisiness levels										
B-737	Takeoff	75.4	76.6	80.1	82.8	88.9	90.8	88.9	79.9	80.2
DC-8 TF	Landing	74.0	74.8	82.5	83.3	89.7	93.9	88.7	79.0	75.5
Concorde	Takeoff	73.0	73.6	77.9	78.5	85.0	86.2	83.4	77.2	75.0
CV-640	Landing	73.7	75.8	83.6	85.5	91.0	95.4	87.4	80.6	73.7
B-747	Landing	71.4	72.4	76.7	78.1	84.8	87.0	85.1	76.4	75.8
CV-640	Takeoff	76.2	76.9	83.3	83.9	90.1	92.5	88.1	81.0	78.0
DC-8 TF	Takeoff	71.9	73.4	76.7	78.1	83.8	86.5	87.8	76.5	79.1
DC-8 TJ	Landing	72.8	73.5	77.8	78.6	85.5	86.7	85.0	77.7	76.4
Concorde	Landing	76.6	76.9	81.6	82.4	89.0	89.7	83.5	81.2	74.5
B-747	Takeoff	72.0	72.2	77.0	78.0	84.2	85.6	86.6	76.4	77.6
B-737	Landing	72.7	74.6	79.5	81.9	88.8	93.1	87.1	78.9	76.4
DC-8 TJ	Takeoff	71.8	72.1	76.6	77.3	83.7	84.9	85.0	76.5	76.7
Standard deviation		1.77	1.81	2.71	2.87	2.76	3.67	1.93	1.89	1.89
Range		5.2	4.8	7.0	8.2	7.3	10.5	5.5	4.7	6.5
Regression analyses of stimuli										
Intercept		-7.228	-7.278	-7.791	-7.765	-8.282	-8.287	-8.070	-8.301	-7.850
Slope		0.0982	0.0976	0.0979	0.0960	0.0950	0.0926	0.0932	0.1057	0.1023
Correlation coefficient . .		0.979	0.977	0.962	0.959	0.962	0.942	0.974	0.975	0.976

TABLE VIII.- RANK ORDER OF RATING SCALES FOR OUTDOOR EXPERIMENT

Rank order	Standard deviation	Range	Correlation coefficient
1	L_{A1}	PL	L_{A1}
2	L_{A2}	L_{A2}	L_{A2}
3	PL	L_{A1}	EPL
4	EPL	EPNL	PL
5	EPNL	EPL	EPNL
6	L_{D1}	L_{D1}	L_{D1}
7	PNL	PNL	PNL
8	L_{D2}	L_{D2}	L_{D2}
9	PNLT	PNLT	PNLT

TABLE IX.- EQUAL NOISINESS LEVELS AND REGRESSION ANALYSES FOR INDOOR EXPERIMENT

Aircraft	Operation	Measured indoor levels		Estimated outdoor levels								
		L_{A1}	L_{D1}	L_{A1}	L_{A2}	L_{D1}	L_{D2}	PNL	PNLT	EPNL	PL	EPL
Equal noisiness levels												
B-737	Takeoff	64.9	70.9	83.5	84.7	88.2	90.9	97.2	99.0	97.3	87.9	87.9
DC-8 TF	Landing	62.5	70.6	84.3	85.1	92.7	93.4	100.0	104.2	99.1	89.0	85.2
Concorde	Takeoff	62.0	67.2	81.3	81.8	86.2	86.7	93.4	94.6	91.8	84.7	82.5
CV-640	Landing	62.5	72.5	83.3	85.4	93.2	95.1	100.8	105.2	97.2	90.2	83.1
B-747	Landing	60.9	66.3	79.6	80.6	84.9	86.3	93.1	95.3	93.5	83.9	83.2
CV-640	Takeoff	69.6	77.5	84.0	84.7	91.1	91.7	98.2	100.5	96.0	88.9	85.6
DC-8 TF	Takeoff	61.4	67.8	80.3	81.7	85.1	86.3	92.4	95.1	96.6	84.3	87.0
DC-8 TJ	Landing	61.3	67.4	79.6	80.6	84.9	85.7	92.8	94.0	92.2	84.3	82.9
Concorde	Landing	64.9	69.9	84.7	84.7	89.6	90.4	97.1	97.7	91.6	88.4	81.9
B-747	Takeoff	61.9	68.9	80.2	80.4	85.2	86.2	92.8	94.1	95.3	84.2	85.4
B-737	Landing	61.6	68.7	82.0	83.9	88.8	91.2	98.2	102.5	96.6	87.8	84.9
DC-8 TJ	Takeoff	60.4	66.5	80.4	80.7	85.2	85.9	92.5	93.6	93.0	84.0	84.4
Standard deviation		2.55	3.15	1.93	2.05	3.14	3.33	3.18	4.22	2.46	2.42	1.85
Range		9.2	11.2	5.1	5.0	8.3	9.4	8.4	11.6	7.5	6.3	6.0
Regression analyses of stimuli												
Intercept		-5.561	-6.313	-7.532	-7.614	-8.024	-8.026	-8.529	-8.445	-8.320	-8.184	-7.907
Slope		0.0884	0.0907	0.0919	0.0919	0.0912	0.0900	0.0891	0.0861	0.0874	0.0947	0.0935
Correlation coefficient . .		0.970	0.957	0.980	0.976	0.958	0.953	0.958	0.933	0.971	0.971	0.981

TABLE X.- RANK ORDER OF RATING SCALES FOR INDOOR EXPERIMENT

BASED ON ESTIMATED OUTDOOR LEVELS

Rank order	Standard deviation	Range	Correlation coefficient
1	EPL	L_{A2}	EPL
2	L_{A1}	L_{A1}	L_{A1}
3	L_{A2}	EPL	L_{A2}
4	PL	PL	EPNL
5	EPNL	EPNL	PL
6	L_{D1}	L_{D1}	L_{D1}
7	PNL	PNL	PNL
8	L_{D2}	L_{D2}	L_{D2}
9	PNLT	PNLT	PNLT

TABLE XI.- EFFECT OF DURATION ON EQUAL NOISINESS LEVELS

FOR OUTDOOR EXPERIMENT

Rating scale	Duration correction	Slope	dB per doubling of duration	Correlation coefficient (a)	Remaining standard deviation
L_{A1}	Estimated	-0.303	0.91	-0.556^{ns}	1.47
L_{A1}	Integrated	-.362	1.09	$-.603^{\dagger}$	1.41
PNL	Estimated	-.488	1.46	$-.657^{\dagger}$	2.08
PNL	Integrated	-.727	2.18	$-.811^{\dagger}$	1.61

[a] ns indicates not significant; † indicates significant at 5 percent.

TABLE XII.- TESTS FOR DIFFERENCES IN SLOPE AND ADJUSTED GROUP MEANS

OF NOISINESS JUDGMENTS BETWEEN CONCORDE AND OTHER AIRCRAFT

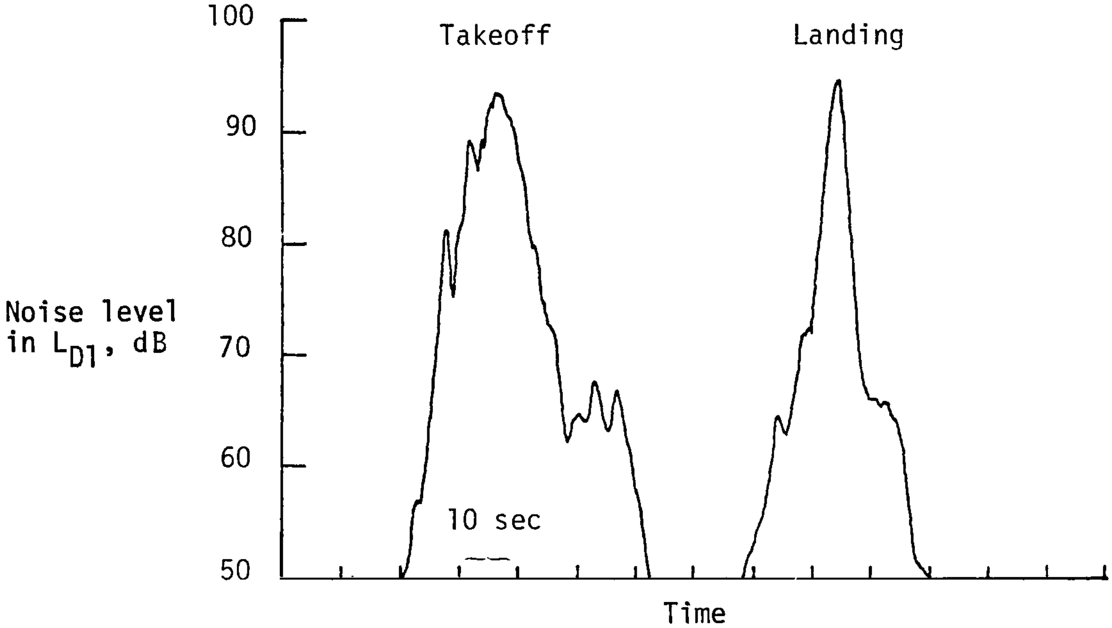
Rating scale	Outdoor experiment (a)		Indoor experiment (a)	
	Slope	Mean	Slope	Mean
Takeoff and landing				
L_{A1}	3.34^{ns}	3.33^{ns}	3.39^{ns}	2.68^{ns}
EPNL	5.07^{ns}	18.48^{1}	4.68^{ns}	20.30^{1}
Takeoff				
L_{A1}	2.41^{ns}	0.25^{ns}	0.03^{ns}	0.24^{ns}
EPNL	3.72^{ns}	11.14^{2}	3.41^{ns}	17.64^{2}
Landing				
L_{A1}	2.00^{ns}	14.96^{2}	2.50^{ns}	6.77^{ns}
EPNL	1.39^{ns}	7.56^{ns}	1.78^{ns}	6.48^{ns}

[a] ns indicates not significant; 1 indicates significant, $F_{1,57}(0.01) = 7.10$; 2 indicates significant, $F_{1,27}(0.01) = 7.68$.

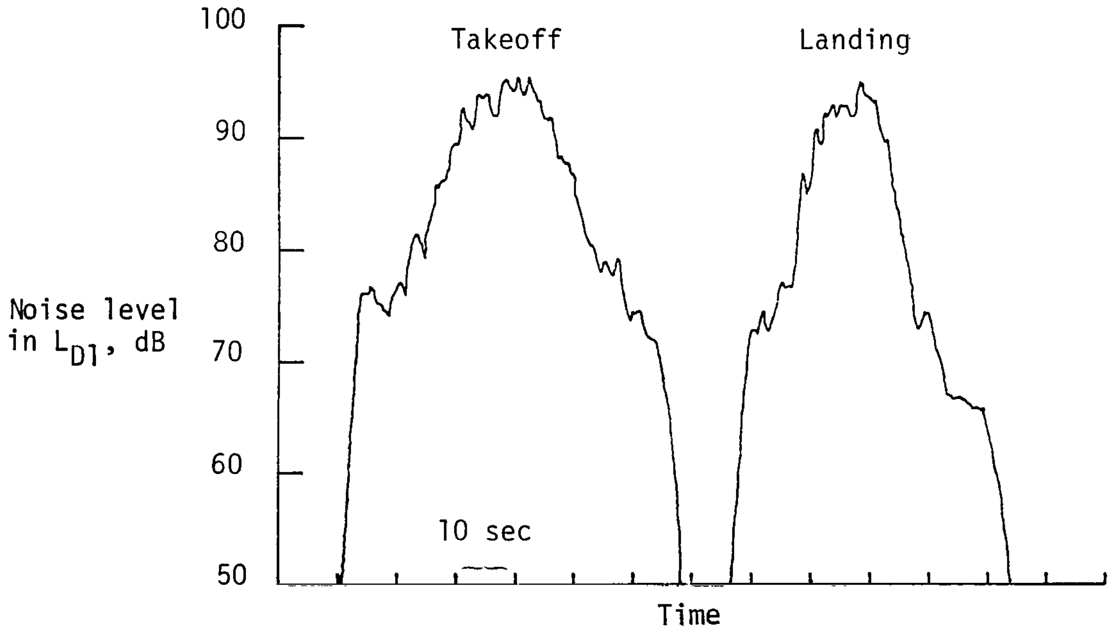
TABLE XIII.- CORRELATION OF EQUAL NOISINESS LEVELS BETWEEN INDOOR EXPERIMENT AND OUTDOOR EXPERIMENT

Rating scale	Regression analysis		Analysis of variance				
	Slope	Correlation coefficient	Source	Degrees of freedom	Sum of squares	Mean square	F
L_{A1}	0.97	0.88	Regression Residual Total	1 10 11	32.2 9.0 41.2	32.2 .9	35.8†
EPNL	1.21	0.95	Regression Residual Total	1 10 11	59.9 6.5 66.4	59.9 .65	92.5†

†Significant at 1-percent level, $F_{1,10}(0.01) = 10.04$.

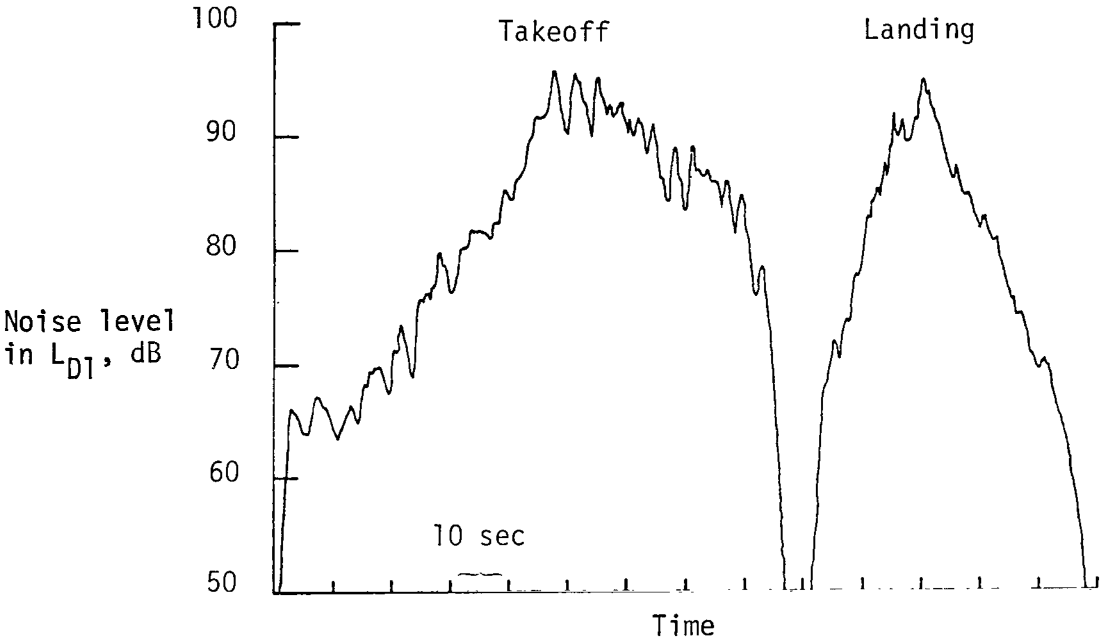


(a) Concorde.

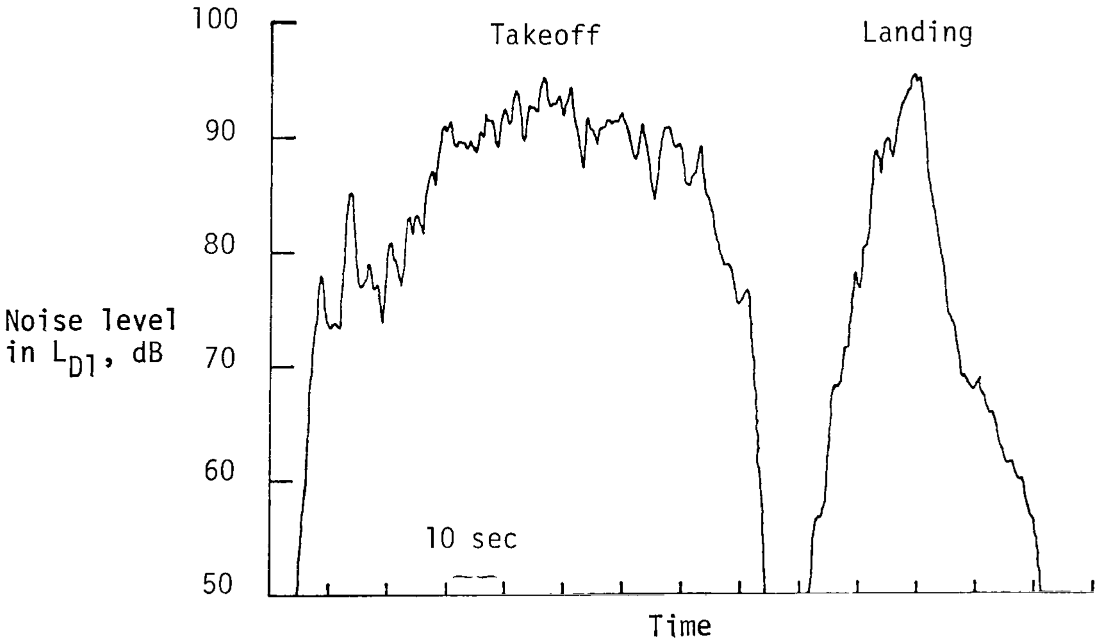


(b) B-747.

Figure 1.- Time histories of aircraft noise stimuli.

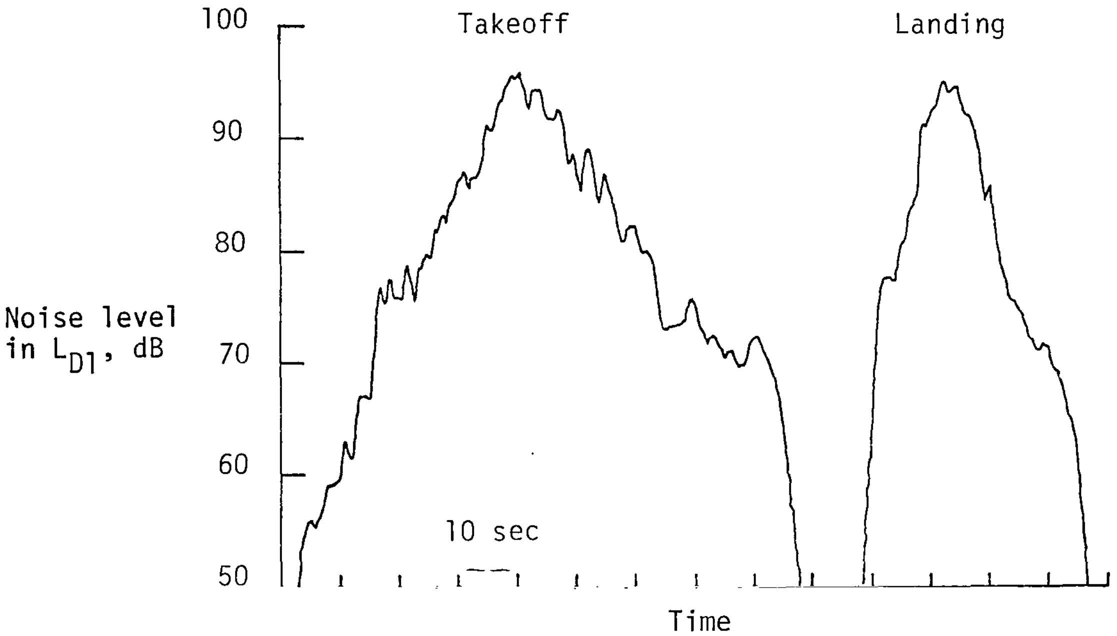


(c) B-737.

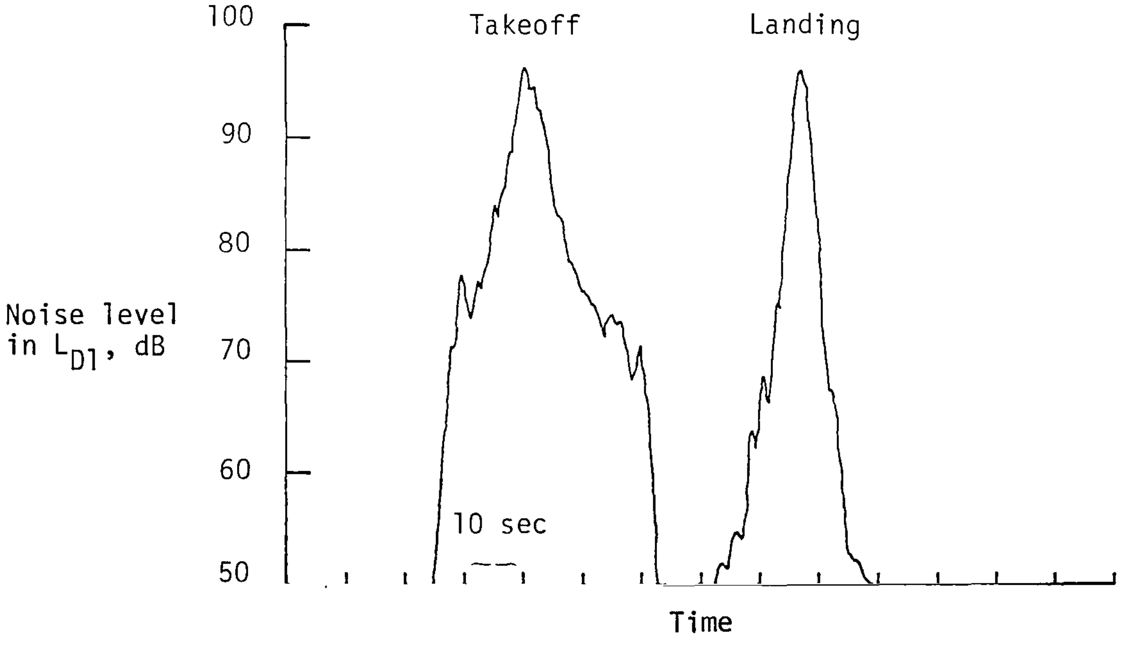


(d) DC-8 TF.

Figure 1.- Continued.

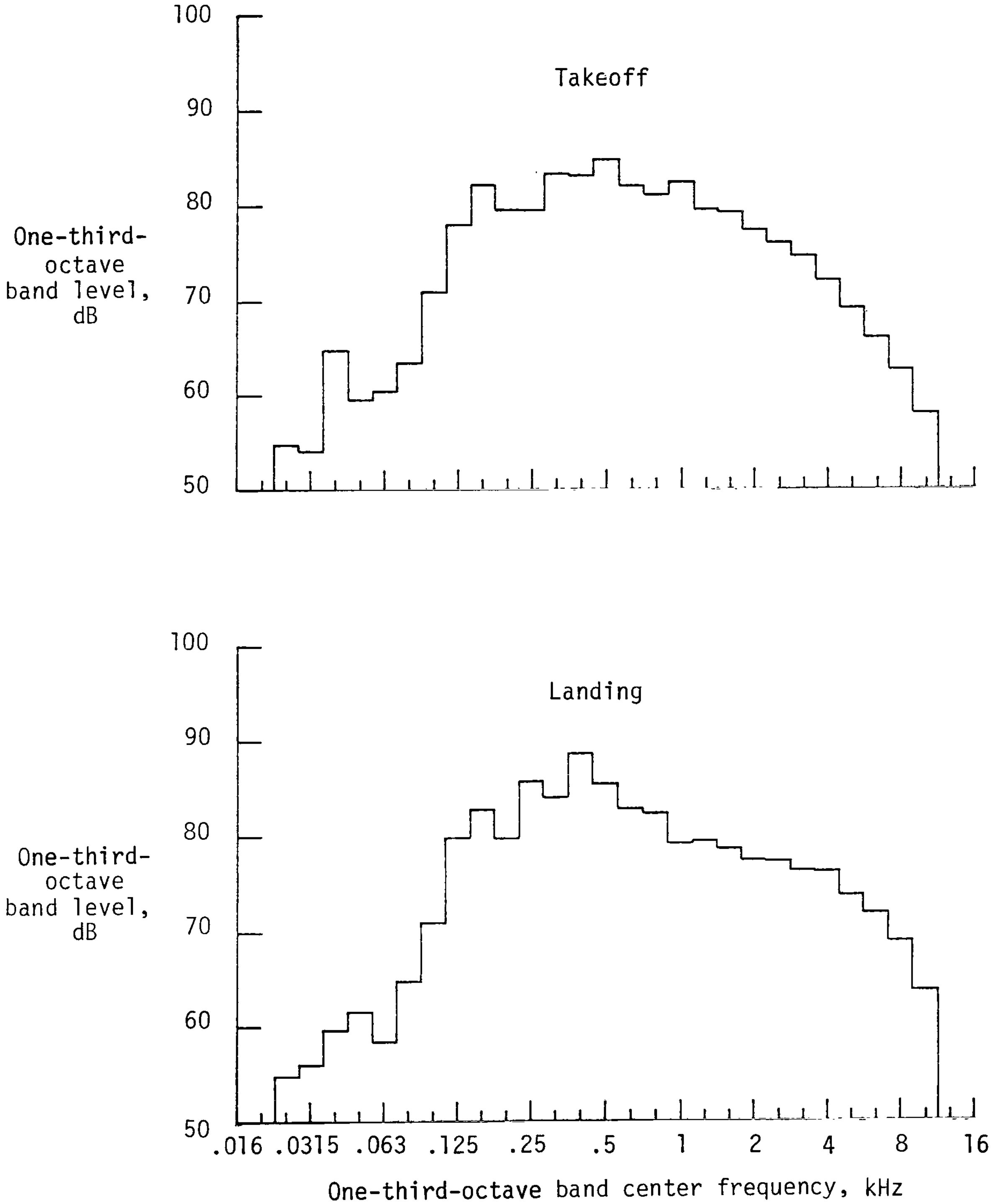


(e) DC-8 TJ.



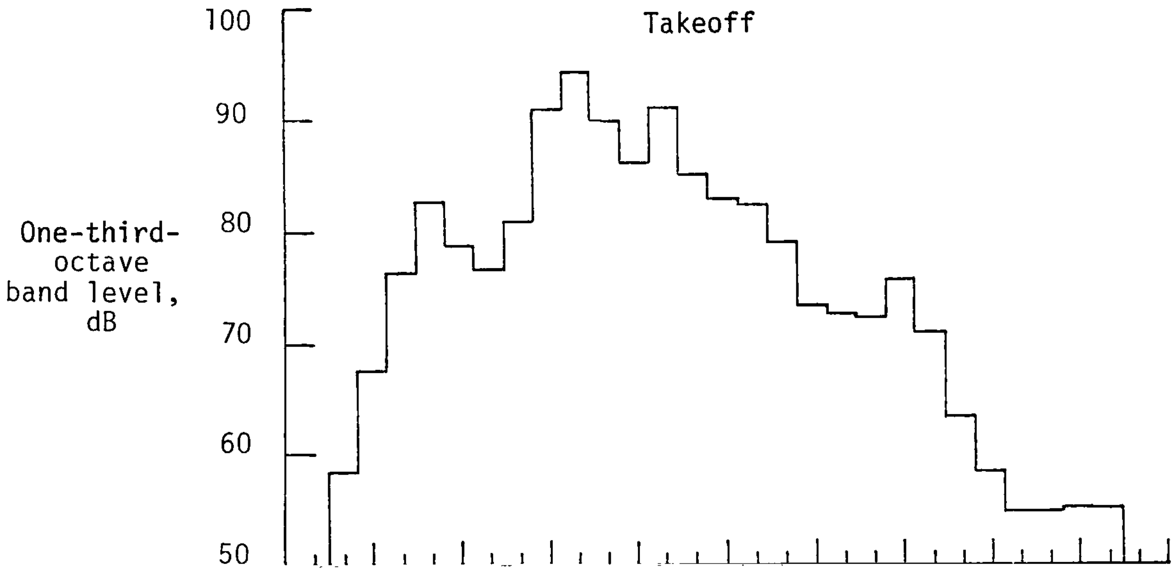
(f) CV-640.

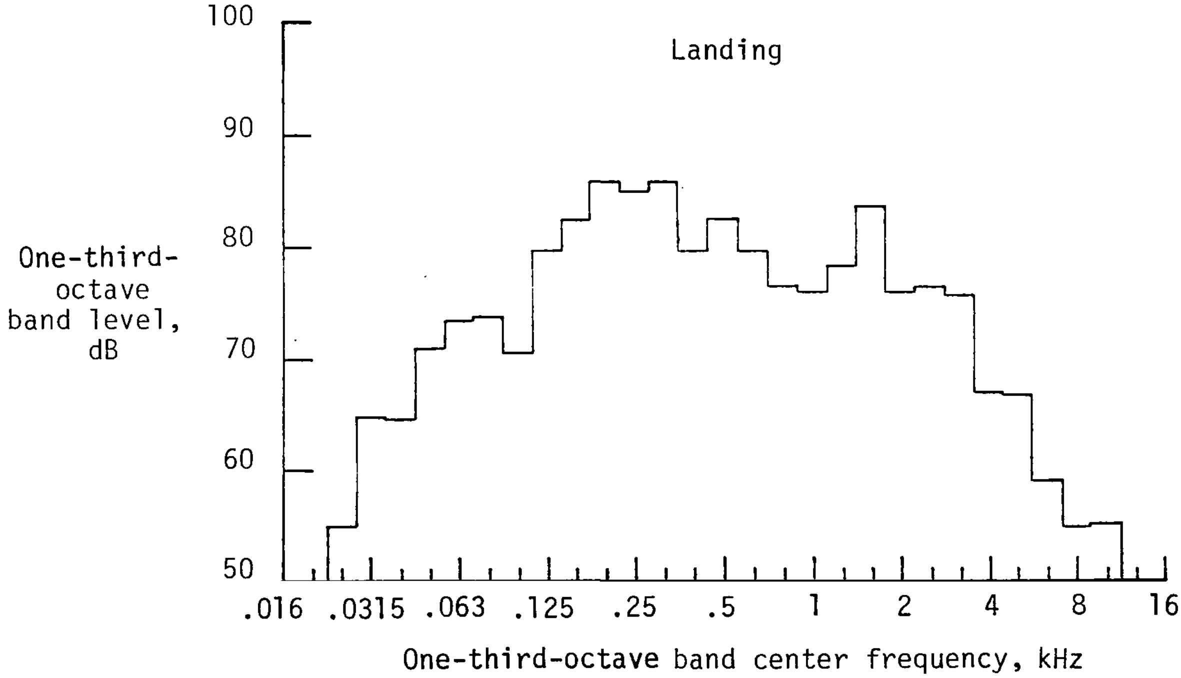
Figure 1.- Concluded.



(a) Concorde.

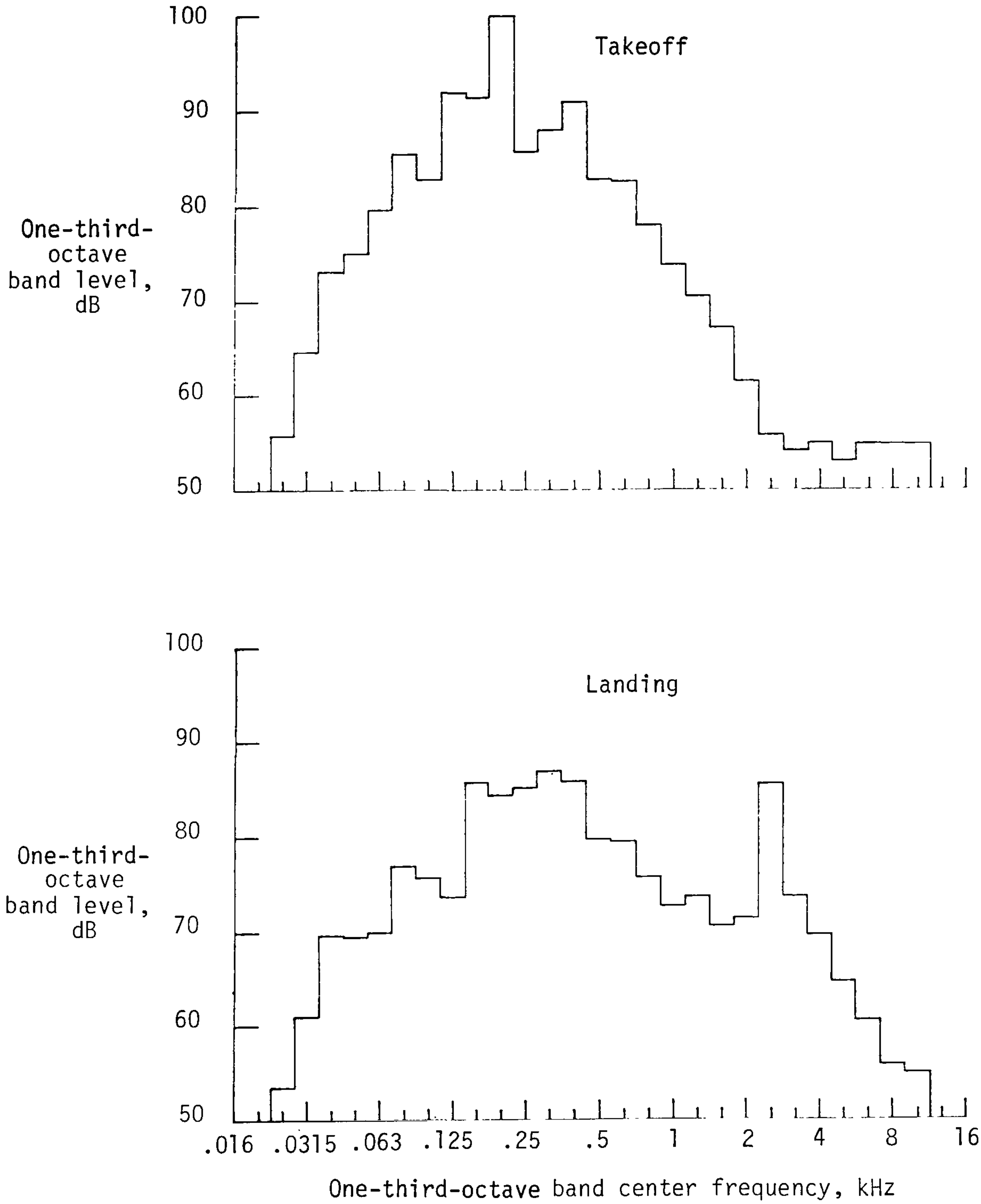
Figure 2.- Aircraft noise spectra, one-third-octave band levels, at peak PNL.





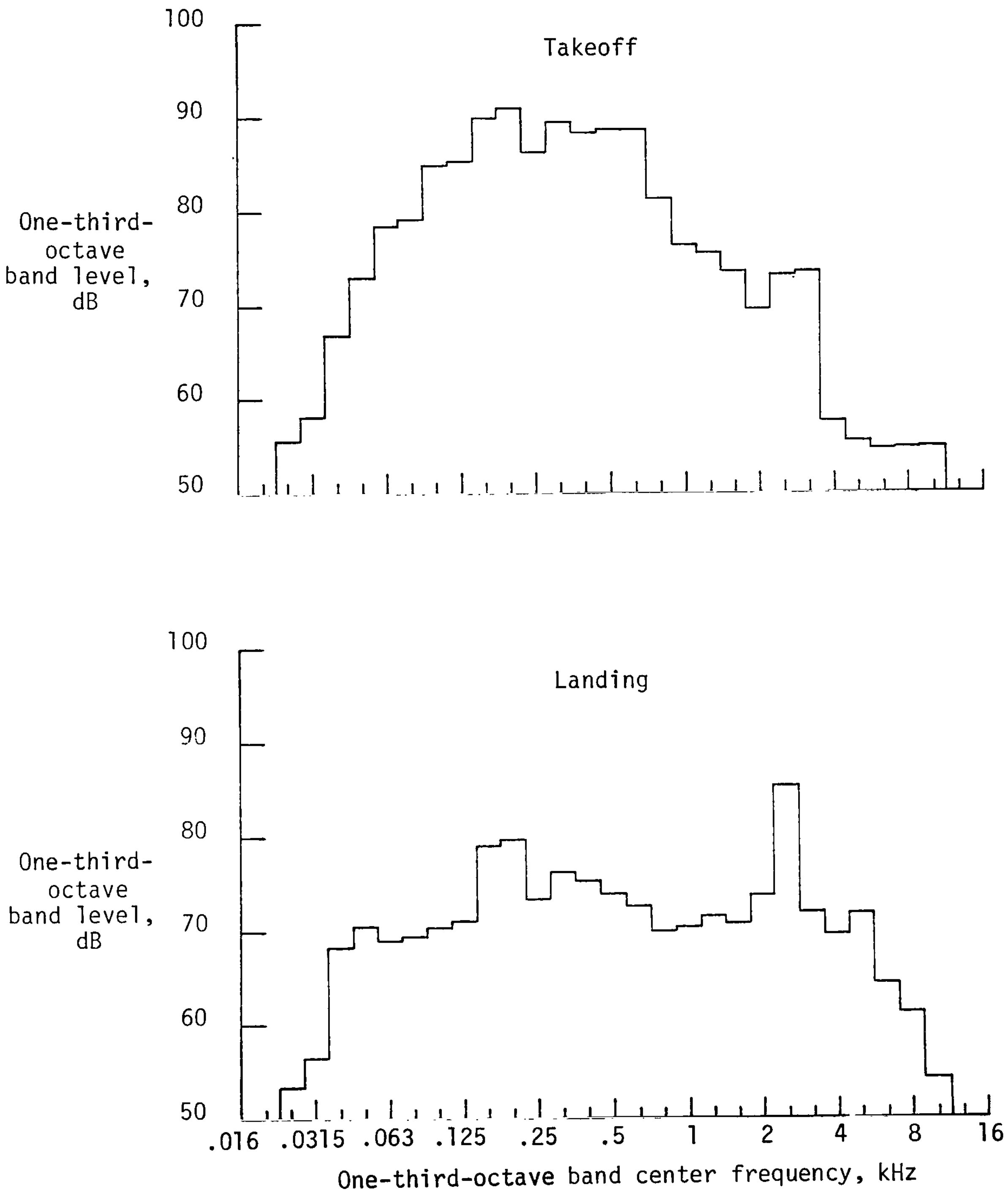
(b) B-747.

Figure 2.- Continued.



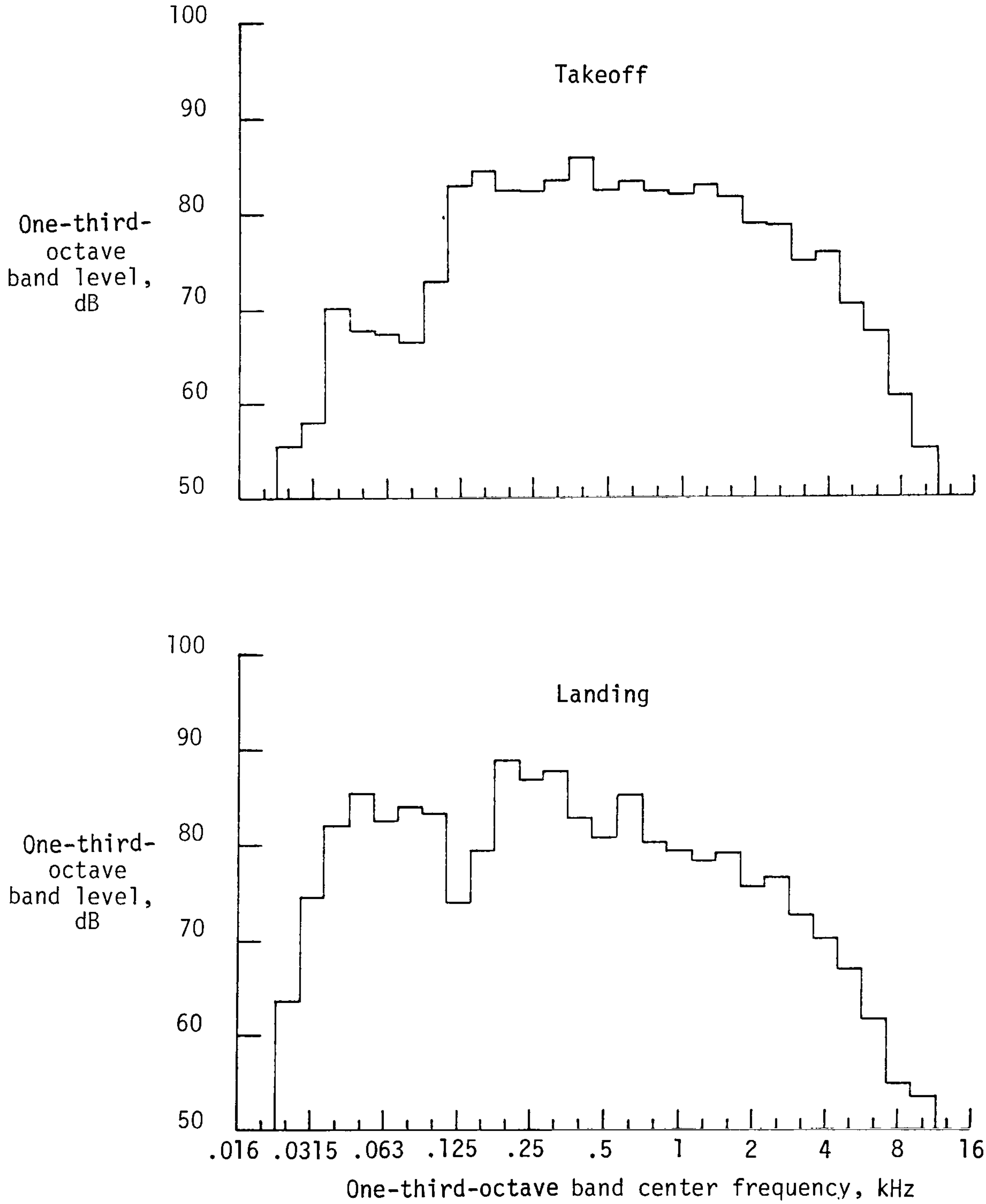
(c) B-737.

Figure 2.- Continued.



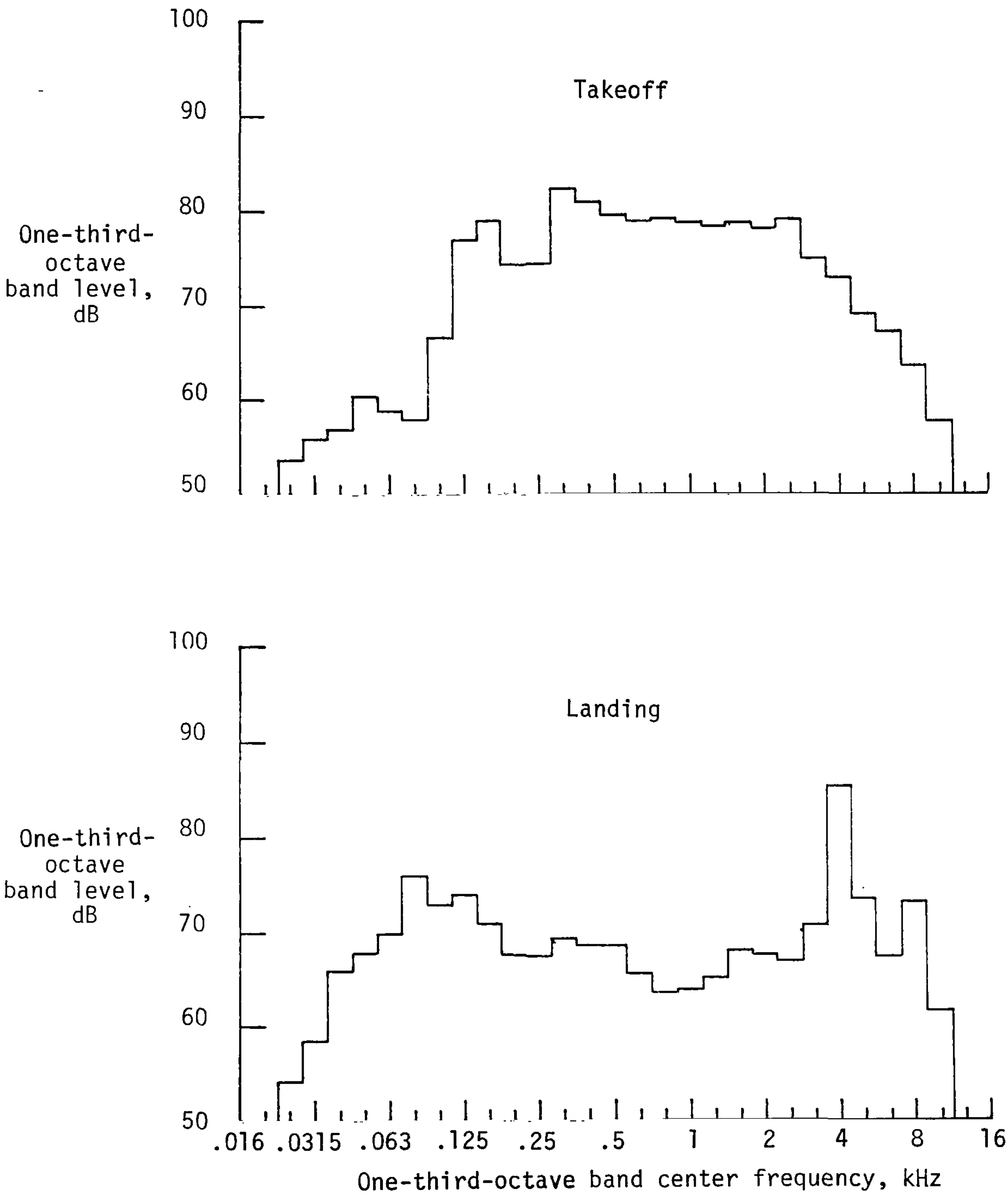
(d) DC-8 TF.

Figure 2.- Continued.



(e) DC-8 TJ.

Figure 2.- Continued.



(f) CV-640.

Figure 2.- Concluded.

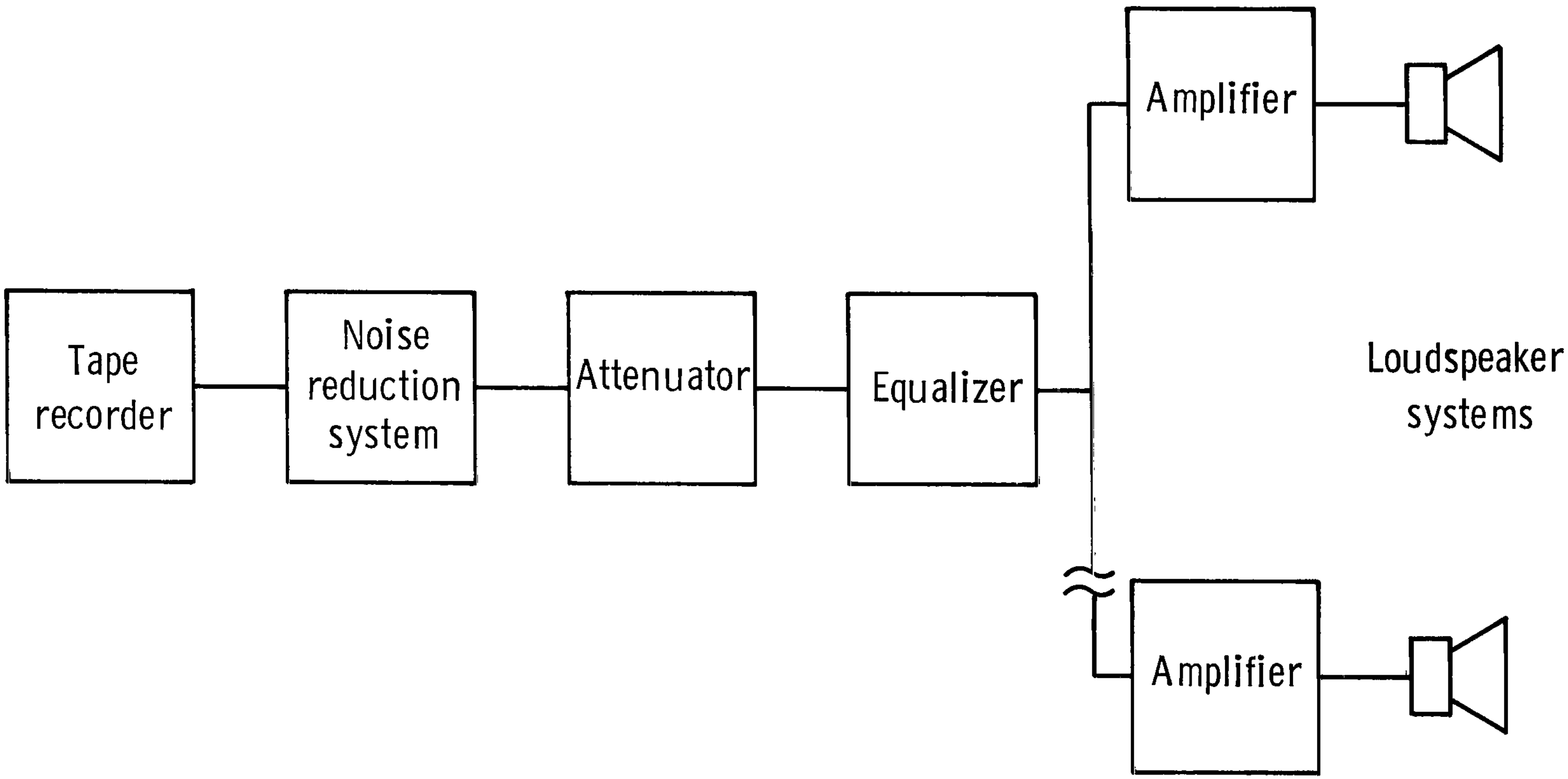
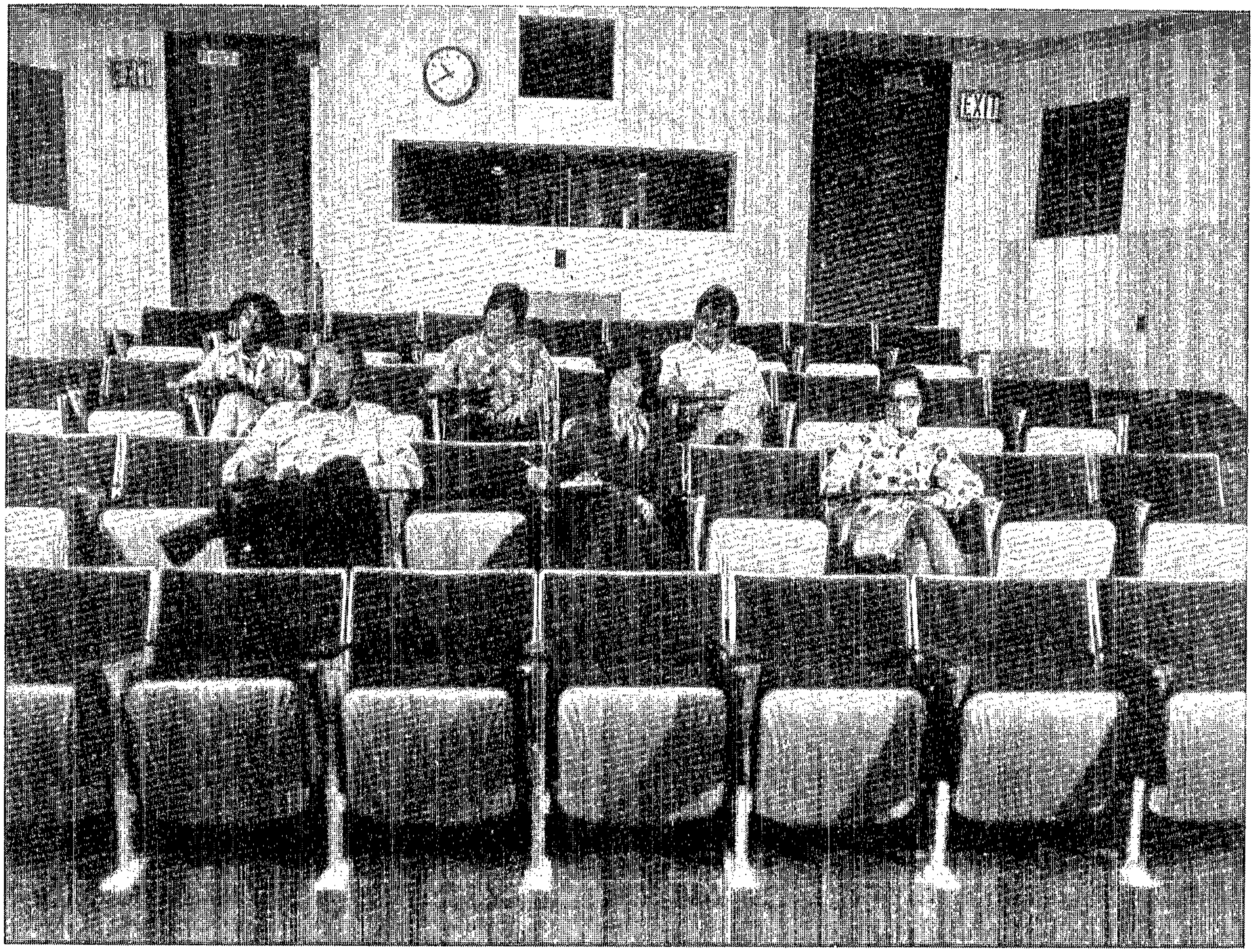


Figure 3.- Block diagram of audio reproduction system.



L-76-3944

Figure 4.- Subjects in Langley exterior effects room.

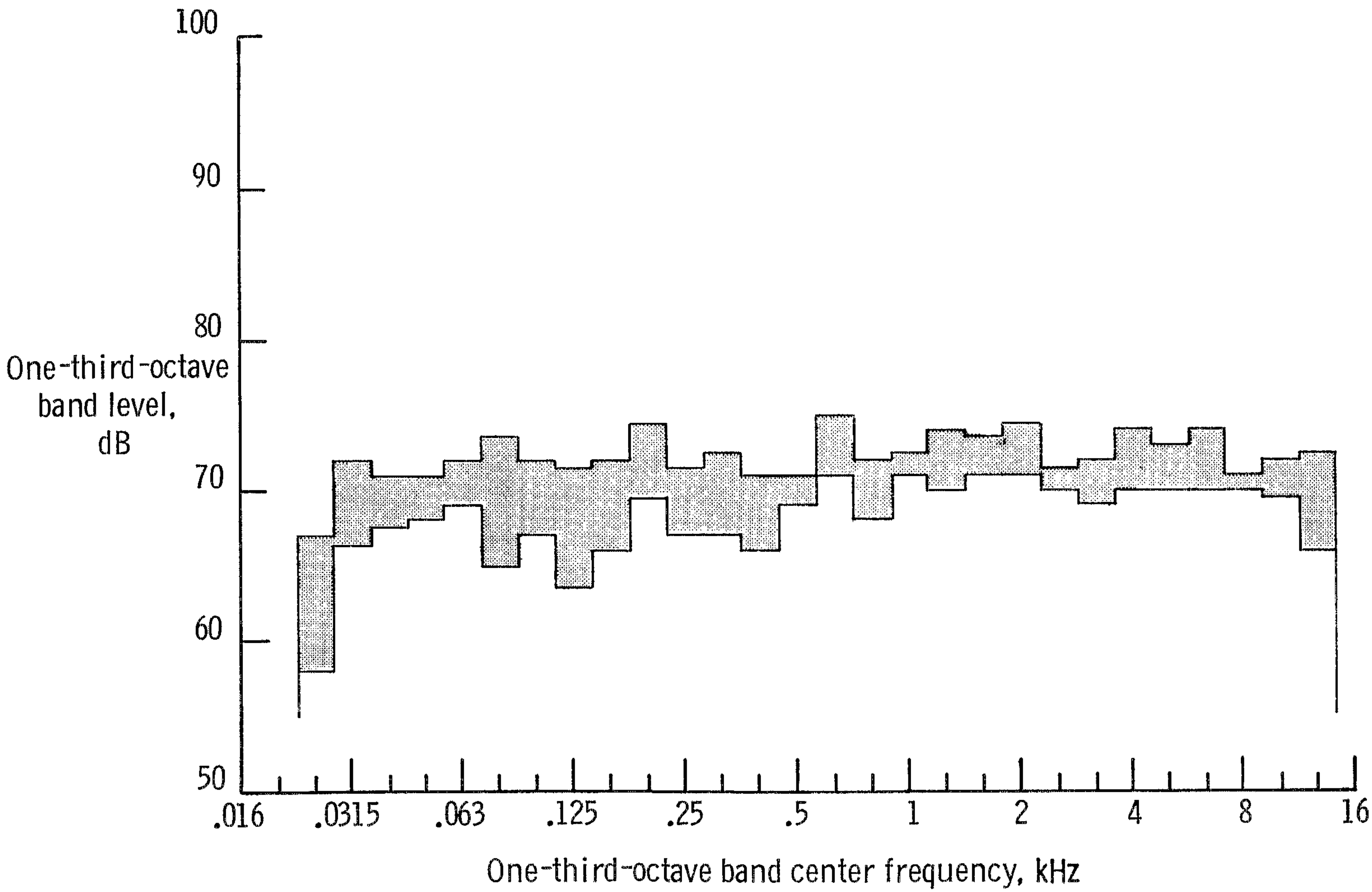


Figure 5.- One-third-octave band response of Langley exterior effects room to pink noise after equalization.

L-76-3945

Figure 6.- Subjects in Langley interior effects room.

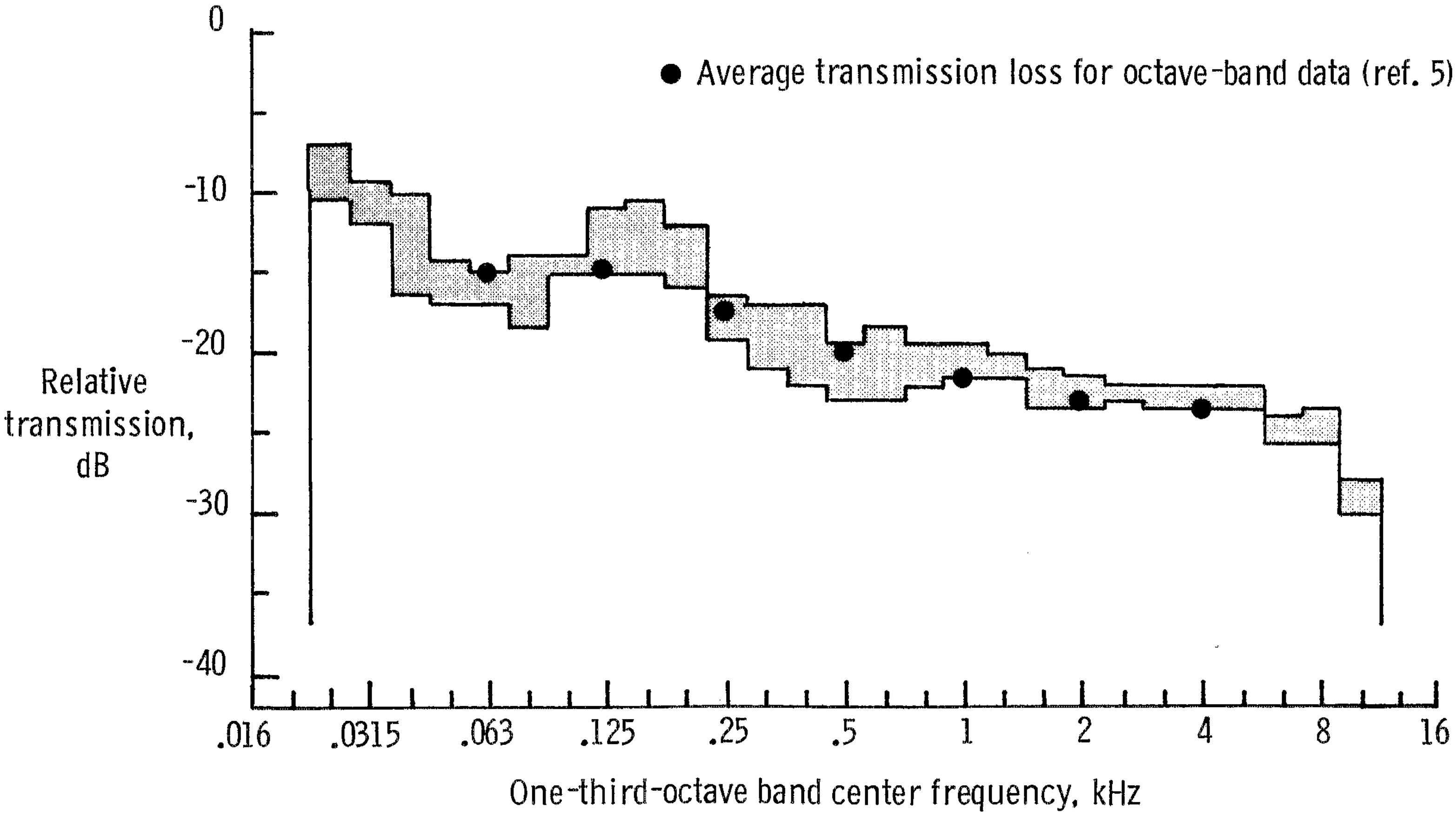


Figure 7.- Relative acoustic transmission for the indoor-simulation facility.

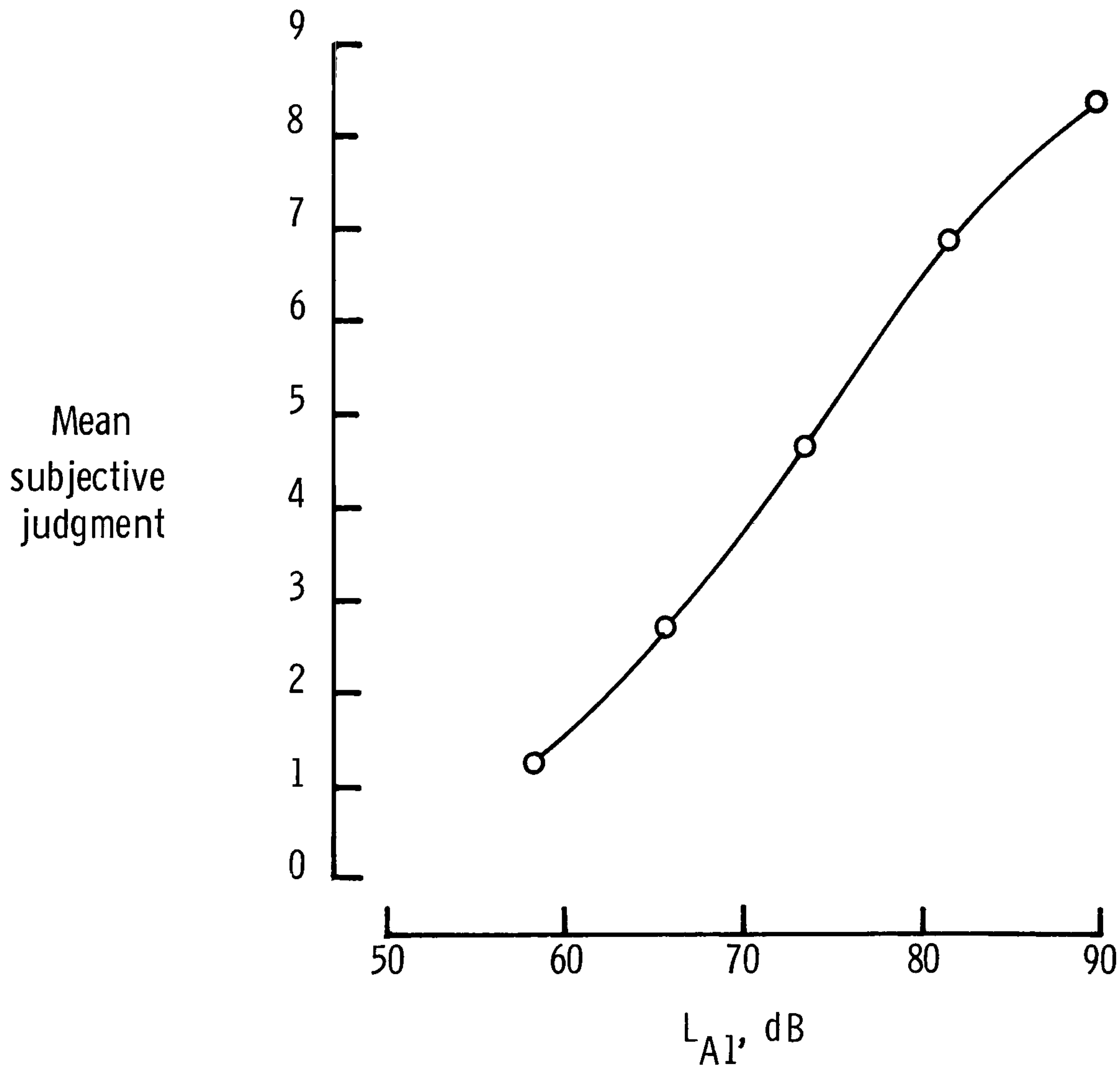


Figure 8.- Mean subjective judgment as a function of rating scale L_{A1} for the Concorde takeoff stimuli in outdoor experiment.

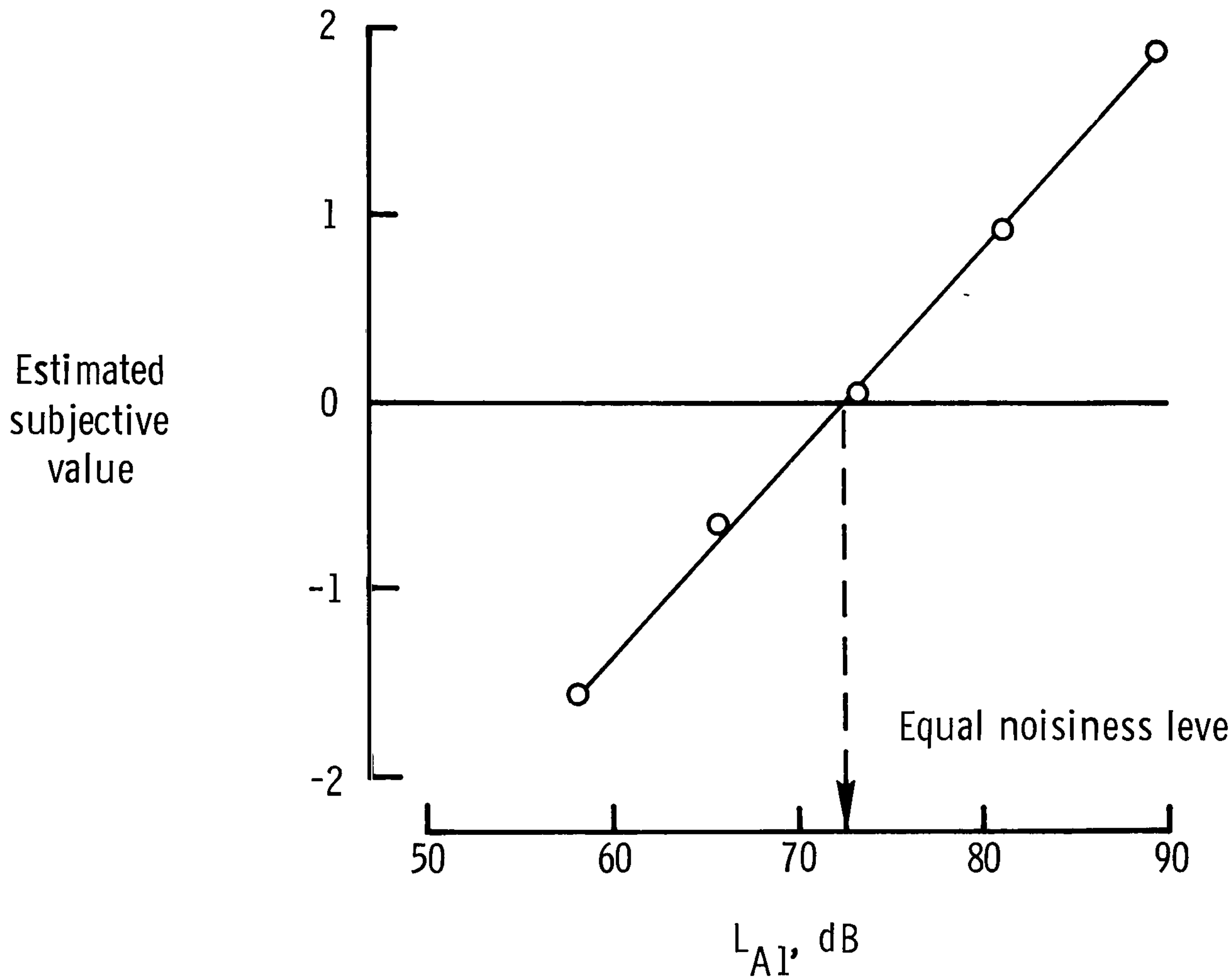


Figure 9.- Estimated subjective value and equal noisiness level from successive intervals analysis for the Concorde takeoff stimuli in outdoor experiment.

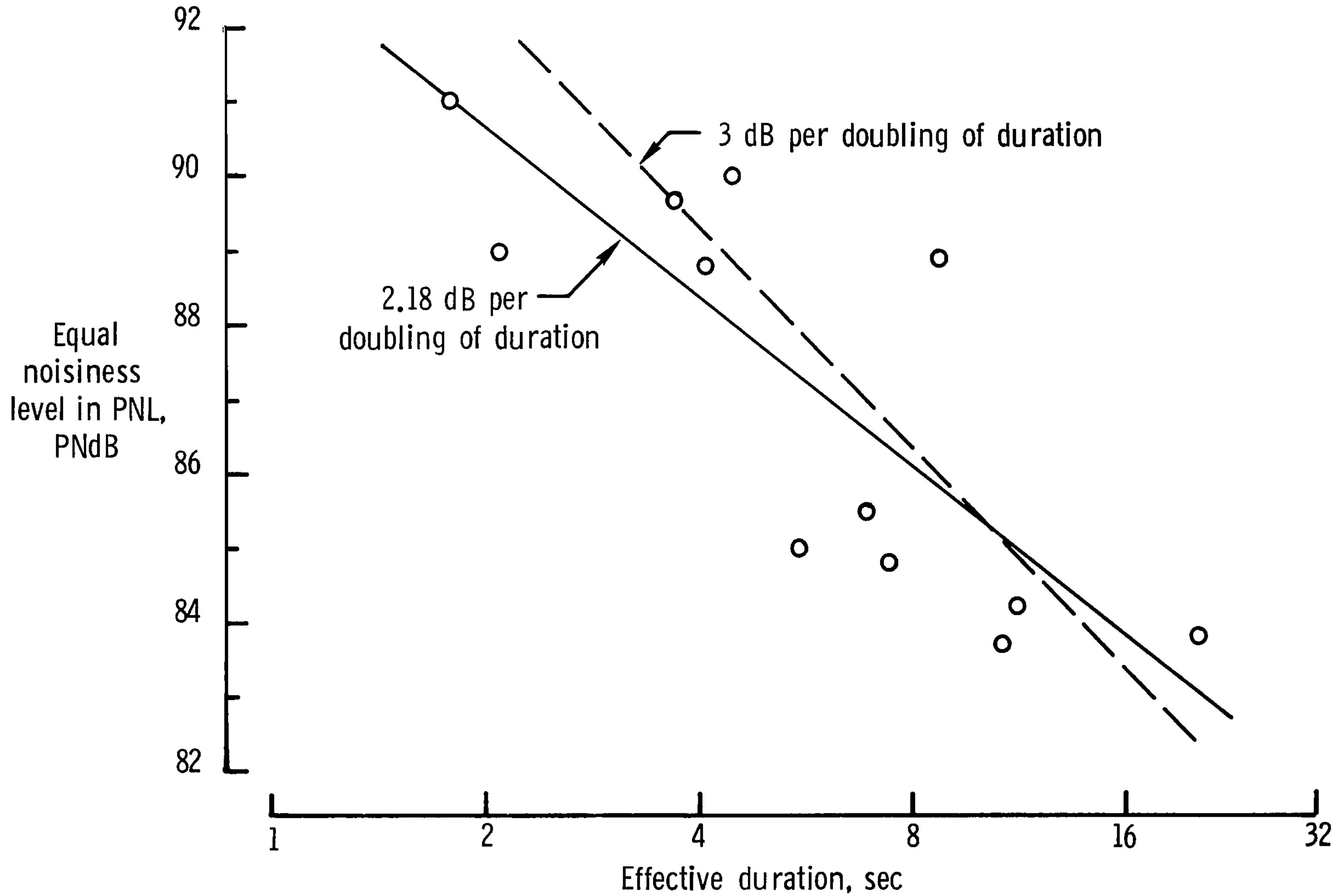
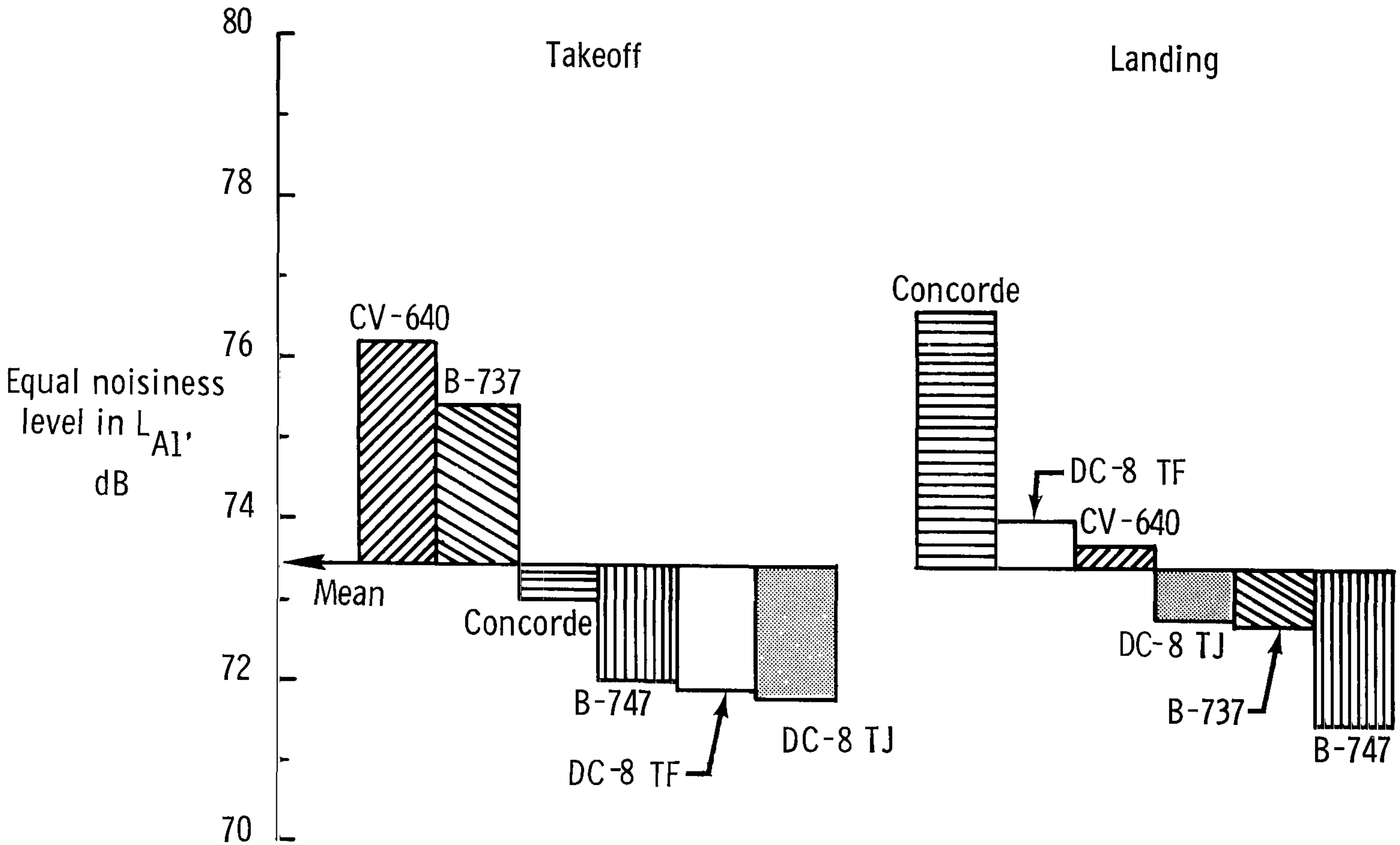
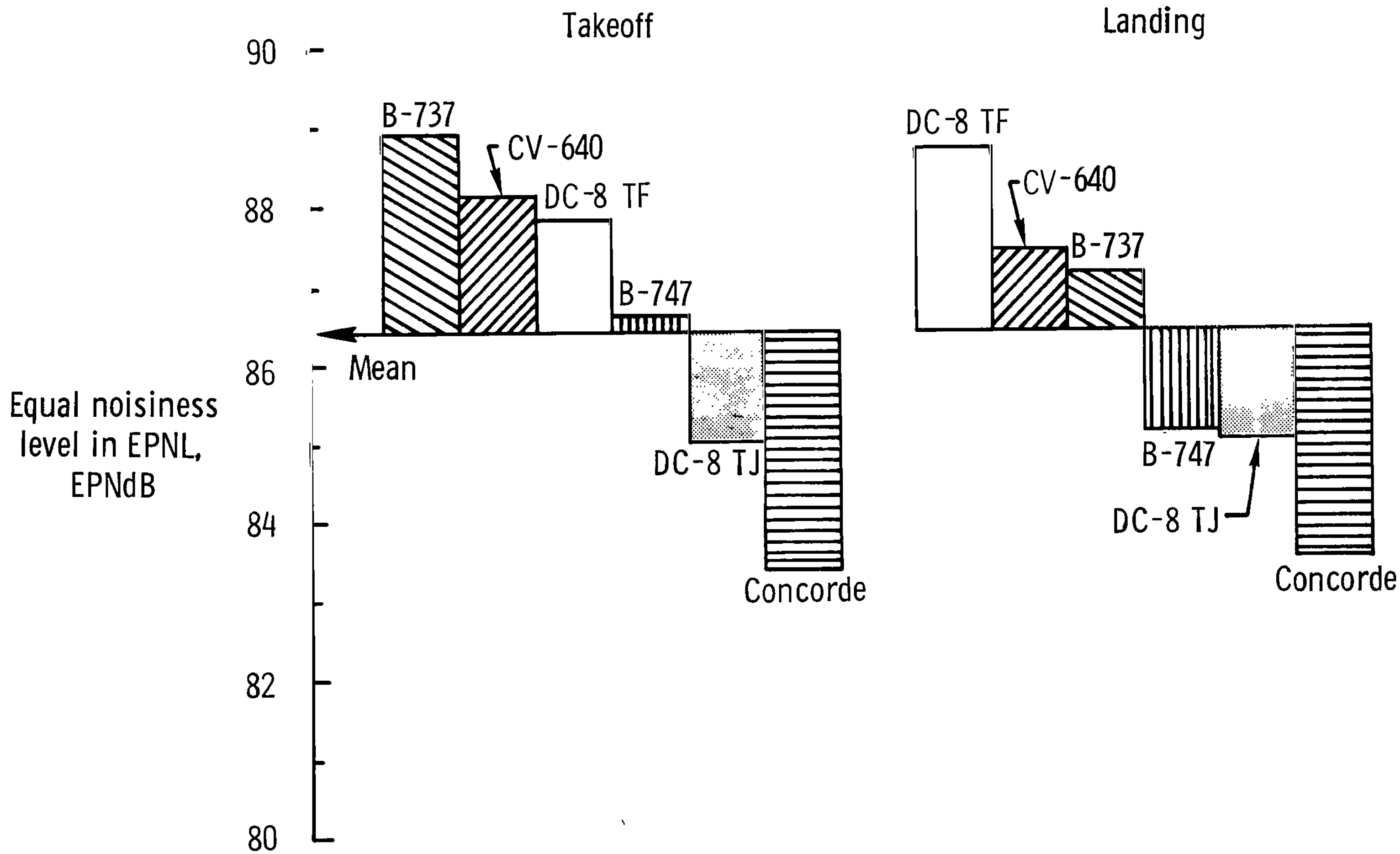


Figure 10.- Effect of noise duration on equal noisiness levels in PNL.



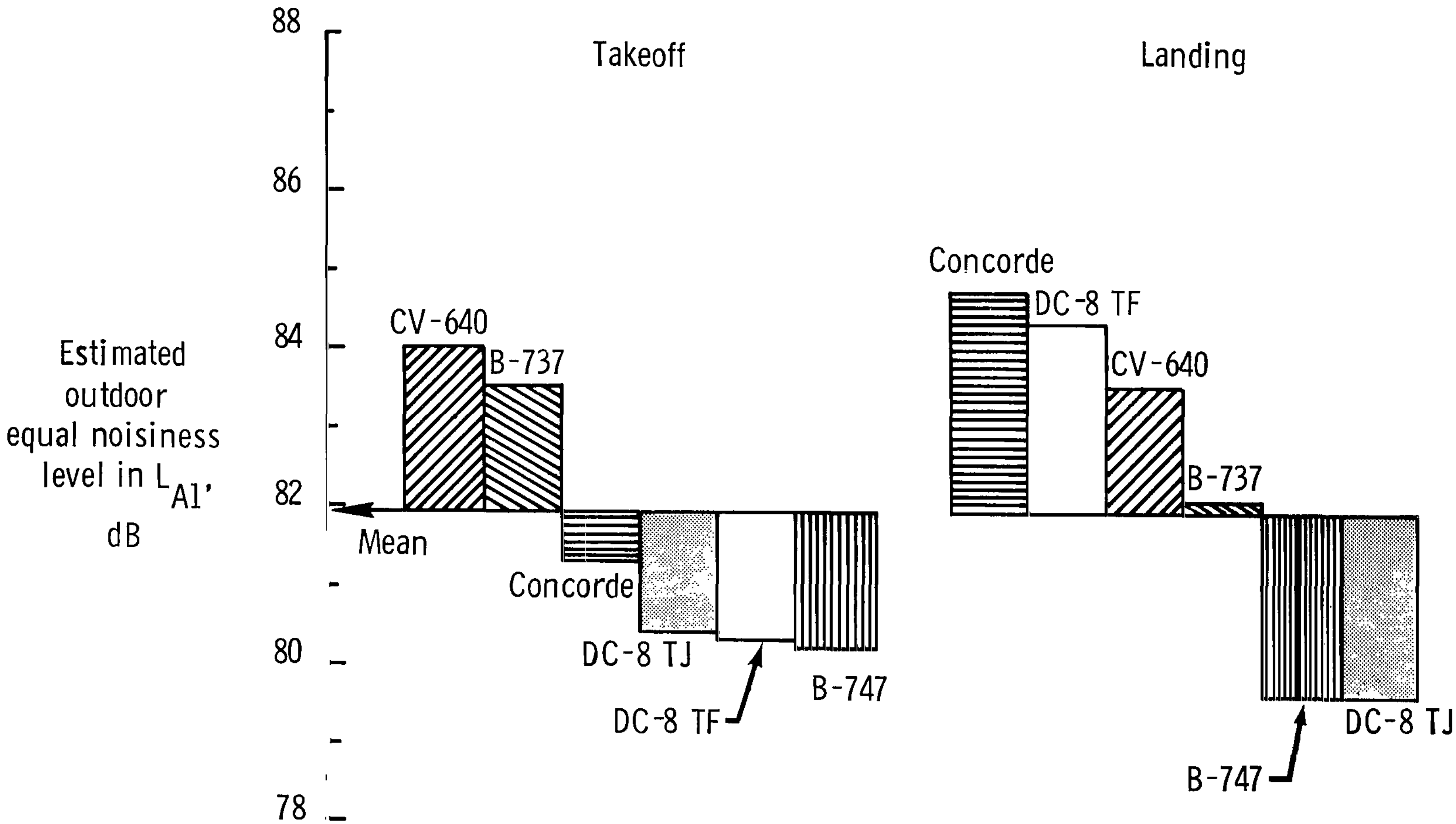
(a) Rating scale L_{A1}.

Figure 11.- Equal noisiness levels for outdoor experiment.



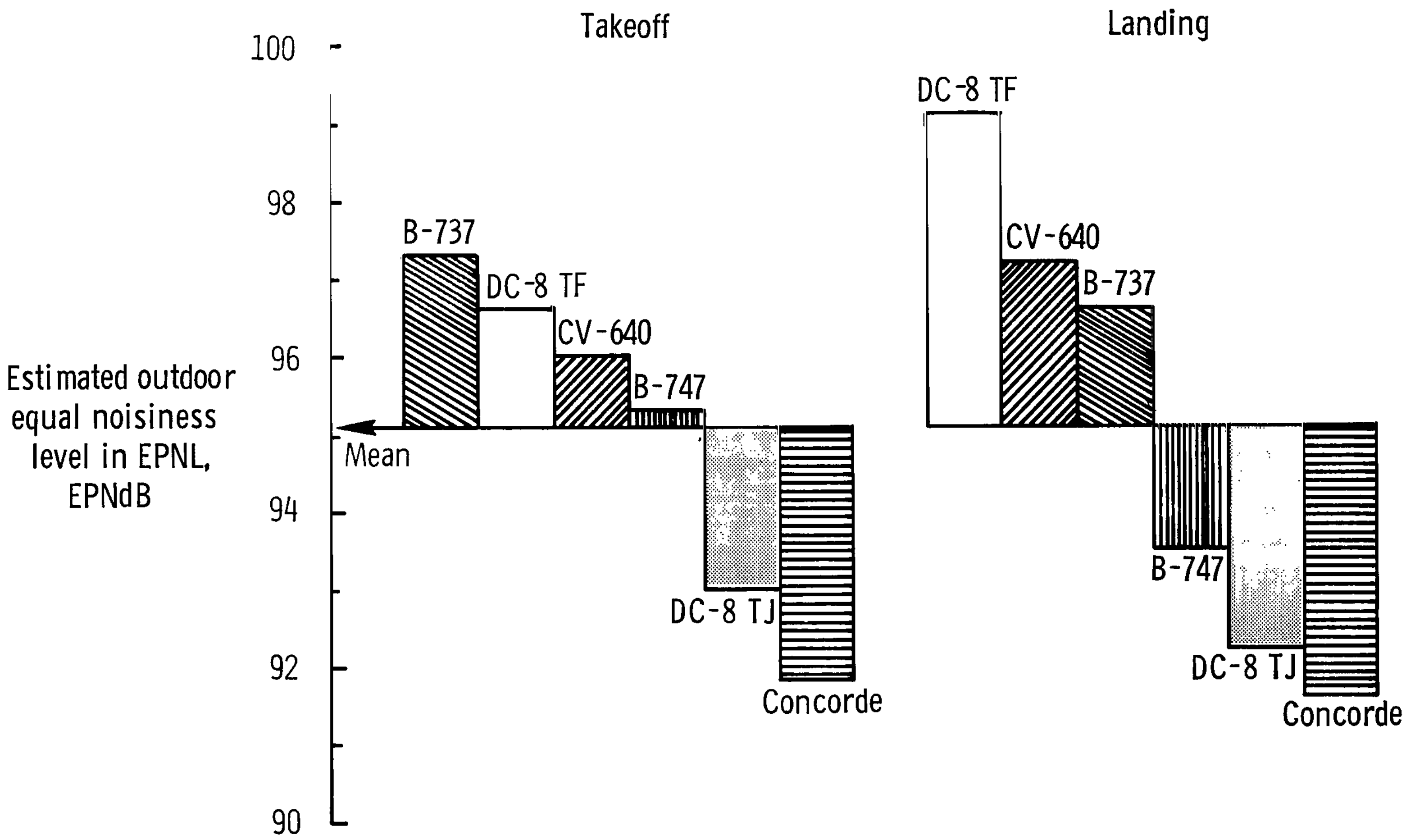
(b) Rating scale EPNL.

Figure 11.- Concluded.



(a) Rating scale L_{A1}.

Figure 12.- Equal noisiness levels for indoor experiment.



(b) Rating scale EPNL.

Figure 12.- Concluded.

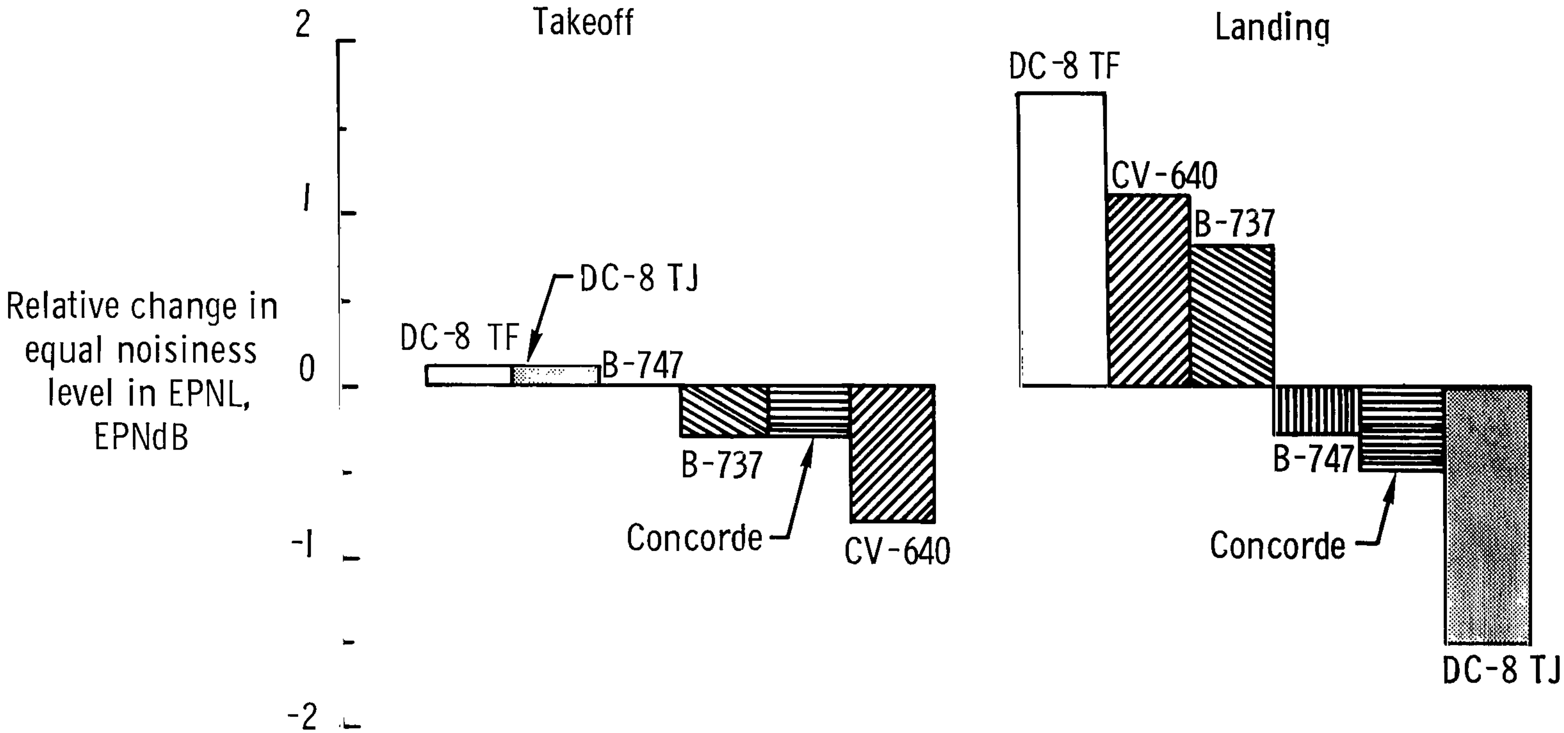


Figure 13.- Relative change in equal noisiness levels from outdoor to indoor simulation for rating scale EPNL.

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